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Coal-Fired Industrial Boiler Inspection Guide

PEDCo-Environmental, Inc., Cincinnati, OH

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16. ABSTRACT

This document provides guidance for evaluating the performance of coal-fired industrial boilers relative to a pollution control agency's particulate air pollution control rules and regulations. The guidance and checklists in this document enable an air pollution control agency inspector to check a boiler operation quickly and efficiently. A thorough description of stoker-fired and pulverized coal-fired industrial boilers helps prepare the inspector for the field inspection. Pollution control equipment typically used on industrial boilers (multicyclones, fabric filters, electrostatic precipitators, and scrubbers) is described as well as common problems and possible solutions that influence the operation and maintenance of these devices.

Baseline data for a boiler and its pollution control equipment normally are established during a compliance stack test. Information contained in this report shows the agency inspector how to compare current boiler operations to the baseline data for a compliance determination. This is particularly useful when a clearly defined cause-and-effect relationship cannot be established for a given source.

17. KEY WORDS AND DOCUMENT ANALYSIS

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Boilers	Industrial, Stoker-fired, Pulverized Coal-fired	13A
Pollution	Air Pollution Control	13B
Particles	Particulate Emissions	14G
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SECTION 1

INTRODUCTION

Coal-fired boilers are widely used in industrial plants throughout the United States to provide process steam, space heat, and electricity in factory and office buildings. Nationwide it is estimated that there are approximately 144,000 industrial coal-fired boilers, equivalent to 25,260 watts or 86,200 x 10^6 Btu/h of capacity. These boilers are within the size range from 20 to 400 x 10^6 Btu/h. At an estimated average capacity factor of 20 percent, these boilers generate about 2.6 x 10^6 tons of particulate matter, 1.7 x 10^6 tons of sulfur dioxide, and 0.3 x 10^6 tons of nitrogen oxides per year. This represents a contribution of 10 percent of total U.S. particulate emissions from manmade sources. The size of this emission category suggests that air pollution control inspectors should devote considerable effort to the evaluation, surveillance, and recommendation of remedial procedures for these sources. Furthermore, if the prices of oil and gas escalate relative to coal in the future, industry may rely on coal to an even greater extent at existing and new facilities, which would further increase the significance of these sources.

Although individual boilers differ significantly in size and design, certain general guidelines are appropriate for their inspection and evaluation. This inspection guide provides information that will enable an air pollution control agency inspector to check a boiler operation quickly and efficiently, and at the same time make a thorough determination of its performance relative to the appropriate agency's particulate air pollution control rules and regulations.

Although coal-fired industrial boilers emit significant amounts of sulfur dioxide (SO_2) and nitrogen oxides (NO_x) as well as particulate matter, the control of SO_2 and NO_x is beyond the scope of this inspection guide. Few industrial boilers are currently subject to SO_2 and NO_x regulations that require the installation of control systems. Thus, this manual is devoted to particulate control for coal-fired industrial boilers within the size range from 20 to 400 Btu/h. Oil-fired and gas-fired boilers are not discussed.

1.1 PURPOSE AND SCOPE

This inspection guide provides technical information and procedures to assist state and local inspectors in conducting compliance inspections and performing evaluations of coal-fired industrial boilers. It includes brief descriptions of several relatively common types of boilers and reference material to assist the inspector in evaluating emission sources. The guide also describes several types of control equipment typically used on industrial-sized boilers and provides several checklists to ensure that important operating factors for this control equipment are not overlooked during the evaluation.

The intent of this guide is to provide inspectors with the necessary information to verify whether sources are meeting their operating permit requirements. Certain portions contain information on combustion parameters that may be used as indicators of source performance between compliance tests. Documented changes in these parameters may be used to indicate whether a source needs to adopt more extensive operation and maintenance (O&M) procedures to ensure continued compliance. When a clearly defined cause-and-effect relationship cannot be established for a given source, documented changes in various operating parameters can support the need for a compliance test. Baseline conditions generally are recorded during a period of known compliance, typically during a compliance stack test; these baseline data include information on boiler operating conditions and key operating parameters of the control equipment.

Each state has adopted a state implementation plan (SIP) describing how it intends to attain and maintain the National Ambient Air Quality Standards (NAAQS). Individual state regulations vary considerably. For example, particulate emission limits for a 10 million Btu/h boiler vary from 0.12 lb/h in Massachusetts to 0.8 lb/h in Iowa. The regulation for Nebraska is fairly typical and is summarized as follows:

A. Existing Equipment:

$Q \leqq 10$ MM Btu/h	0.60 lb TSP/MM Btu
$10 < Q < 3800$ MM Btu/h	$E = 1.026Q^{0.233}$ lb TSP/MM Btu
$Q \geqq 3800$ MM Btu/h	0.15 lb TSP/MM Btu

B. New Equipment (constructed after 8-17-71) 0.10 lb TSP/MM Btu

The purpose of this industrial boiler manual is to aid inspectors in obtaining continuing compliance with local regulations.

1.2 COMPLIANCE INSPECTIONS

Compliance inspections can be conducted at various levels of detail, depending on agency resources and the agency's assessment of the significance of a particular source. A very simple inspection might include only the observation of visible emissions from all of the boiler stacks at a plant. A more complete inspection would include a walk-through of the plant, during which visible emissions would be read and some information obtained concerning the boiler, its control equipment, and operating and maintenance schedules. In a very detailed inspection, the inspector would use test equipment to estimate air and exhaust gas flow rates, oxygen levels, pressure drops, etc. The inspector would also record information on power consumption by control equipment and compare plant records with readings obtained during previous inspections. Calculations based on the information obtained during the inspection would be used to determine whether a stack test is warranted.

A visible evaluation of emissions should be made according to EPA Method 9 or a corresponding state procedure. Thus, an established change in opacity from previously established baseline conditions could be used to indicate whether some operating parameter or group of parameters has changed. A significant increase in opacity could also indicate the need for a more detailed inspection.

Worthwhile operating data on the boiler and its control equipment include fuel characteristics, oxygen and carbon monoxide concentrations in the flue gas, flue gas temperatures, scrubber inlet and outlet temperatures, water flow rates, pressure drop if a scrubber or multicyclone is used, electrostatic precipitator parameters, etc. Boiler parameters such as firebox draft stream flow, fuel rate, temperatures, etc., should be recorded also. Unfortunately, all of these data may not be routinely available. For example, few installations are likely to monitor carbon monoxide regularly, even though its measurement is simple and useful for combustion air adjustment. Where scrubbers are used, the inspector should be concerned with any significant change in the scrubber pressure drop or the liquid-to-gas ratio. The inspector also should check the scrubber pumps, water pressure indicators, and the water flow into the settling pond or tank. The flue gas flow rate is related to the fuel firing rate and can be estimated from the boiler data.

This manual does not describe how to perform different levels of inspections for each control device. Since the reference documents used in the preparation of this manual do not describe inspection levels for all four types of control equipment, it was beyond the scope of this guide to develop the level of inspection checklists for each boiler and control device type. However, the checklists in the Appendix can be modified by the inspector for different levels of inspections.

SECTION 2

COAL-FIRED BOILER PROCESSES

Industrial coal-fired boilers are widely used in many sections of the country. Although their popularity tends to fluctuate with fuel supplies, fuel costs, mining regulations, and environmental policies, these units are expected to be used for many years to come. Despite recent trends toward cleaner fuels such as oil, gas, or electricity, a large amount of coal not only will continue to be burned for industrial purposes in the foreseeable future, but the amount of coal used for this purpose is quite likely to increase. Local agency inspectors will be responsible for ensuring that these industrial coal-burning units are operated in a manner that minimizes the emission of air pollutants.

Combustion in a boiler is the controlled oxidation of the carbon, hydrogen, and sulfur contents of coal to release heat, which is extracted as steam via heat exchangers. The quantity and quality of the steam produced are a function of the boiler design, its state of repair, and operating conditions. Heat exchange efficiencies and steam quality are regulated by combustion conditions, which include coal feed, air distribution, water flow distribution, etc. Although the coal's sulfur content is a relatively minor source of heat, it is very significant in terms of corrosion and pollution. Theoretically, the other two chemical elements, carbon and hydrogen, combine with oxygen and burn to completion according to the following reactions:

$$C + O_2 = CO_2 + 14{,}100 \text{ Btu/lb of C}$$

$$2H_2 + O_2 = 2H_2O + 61{,}100 \text{ Btu/lb of } H_2$$

Air is the source of oxygen for coal-fired boilers. As shown, the combustion reactions are exothermic, and they release about 14,100 Btu/lb of carbon burned and 61,100 Btu/lb of hydrogen burned.

Efficient combustion releases as much of this heat as possible while minimizing losses from incomplete combustion and excess air. For complete combustion to occur in a minimum of excess air, three requirements must be satisfied: the temperature must be high enough to ignite the constituents, there must be sufficient turbulence for complete mixing, and there must be sufficient time for the combustion reactions to reach completion. These factors are often referred to as the "three T's" of combustion. An understanding of combustion and certain empirical and theoretical combustion relationships allows an inspector to make a proper evaluation of a steam generating plant and its performance characteristics. Various combustion concepts are integrated into the discussions that follow.

Several factors influence a plant's decision as to whether to fire pulverized coal or to use one of several different types of stokers. The practical steam-output limit of boilers equipped with mechanical stokers is about 400,000 lb/h (although many engineers limit the application of stokers to somewhat lower steam capacities). Within their capacity range, mechanical stokers are well suited for the production of steam or hot water. When applicable, stokers are often preferred over pulverizers because of their greater operating range, their capability of burning a wide range of solid fuels, and their lower power requirements. In addition to almost any coal, many byproducts and waste fuels (e.g., coke breeze, wood wastes, wood bark, and bagasse) can be burned successfully in stoker-fired boilers. However, pulverized coal-fired boilers can change load more rapidly.

Figure 1 shows a simplified cross section of a typical industrial, natural-circulation boiler. As the coal is burned on a grate or in suspension above the grate, heat is released and transferred to water-filled boiler tubes by radiation and convection. Combustion air below and above the grate is adjusted by the use of dampers to achieve optimum combustion and to minimize smoke generation. The steam-water mixture that forms in the water tubes in the refractory walls of the boiler (risers) passes into an optional separation drum at the top of the boiler, as shown in the figure, and then into a final separation drum (called a steam drum) if there is no intermediate separation drum. Downcomers from the steam drum recirculate water to the mud drum at the bottom of the boiler. Sludge and solids that accumulate in the mud drum are discharged with dissolved water impurities through a blowdown line at the bottom of the mud drum. Feedwater (to replace water and steam losses, blowdown, etc.) is metered into the steam drum via a level controller.

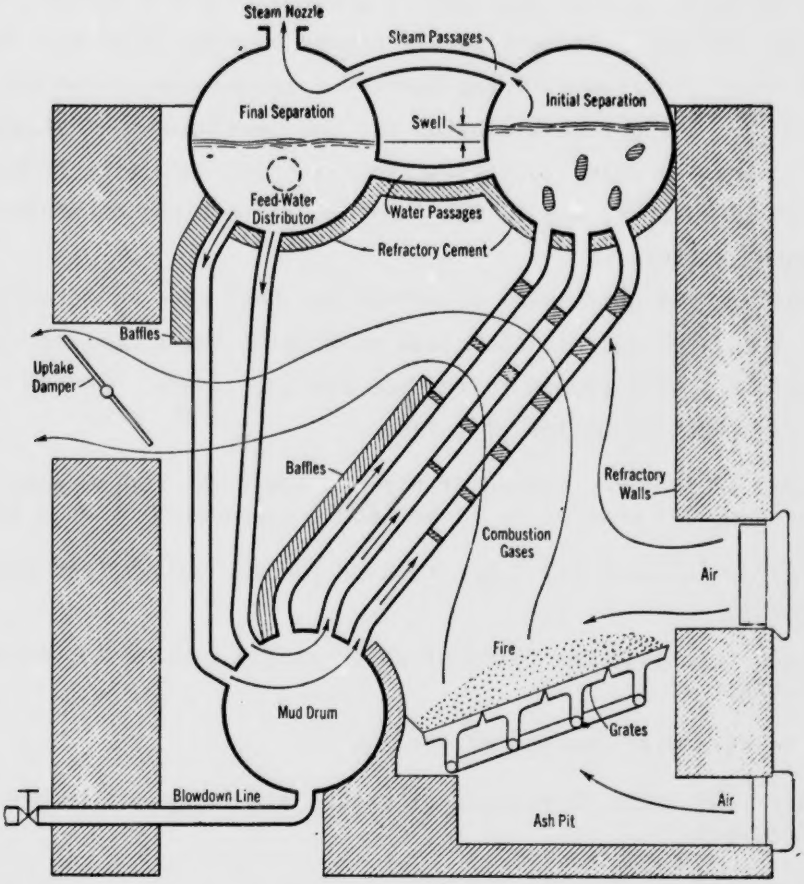

Steam Nozzle
Steam Passages
Final Separation
Swell
Initial Separation
Feed-Water Distributor
Water Passages
Refractory Cement
Baffles
Uptake Damper
Baffles
Refractory Walls
Combustion Gases
Air
Fire
Grates
Mud Drum
Air
Blowdown Line
Ash Pit

Figure 1. Basic water-tube boiler arrangement.

2.1 STOKER-FIRED BOILERS

Early in the history of the steam boiler, mechanical stokers were developed as an improvement over hand-firing. Most small and medium-size industrial boilers are fired with stokers. Several types of stokers are available, but all are designed to feed fuel onto a grate within the furnace and to remove the ash residue. Stokers permit higher burning rates than with hand-firing, and their continuous firing permits improved combustion control and high efficiency. The greatest impetus for the development of stokers came from two sources: 1) objections to smoke emissions resulting from hand-firing and imperfect combustion, and 2) the inherent limitations on steam output from manually stoked boilers.

Over the years a great deal of effort has been made to maximize furnace efficiency; i.e., to convert into steam as much of the combustion-released heat as possible. With regard to furnace design, several factors have been identified as affecting boiler efficiency:

1. Type of fuel and method of firing; i.e., the use of coal, oil, or gas, and whether it is burned in suspension or on a grate.
2. Energy released per cubic foot of furnace volume (per unit of time).
3. Cold fraction, the ratio of water-cooled surface to refractory surface.
4. The size distribution of the coal.
5. Air-fuel ratio (A minimum of excess air is generally preferred.)
6. Temperature of preheated air.
7. Heating value of the coal.
8. Type of water wall.
9. Geometrical considerations, such as positions of tubes and burners.
10. Cleanliness of furnace, especially the surfaces of water-cooled tubes.
11. The ash fusion temperature of the coal; i.e., the temperature at which the coal ash melts and forms slag.

The maximum allowable heat release per unit of grate area for a given stoker type and capacity has been determined by experience. Table 1 lists recommended fuel burning rates (Btu/h per ft_2 of grate area) for various types of stokers, based on the use of coals suited to the stoker type in each case. Furnace heat-release rates for spreader stokers are limited to 25,000 to 32,000 Btu/h per ft^3 of furnace volume; the lower value is the more conservative. Coals that have lower ash fusion temperatures generally require lower furnace heat-release rates.

TABLE 1. MAXIMUM ALLOWABLE FUEL BURNING RATES.

Type of Stoker	Btu/h per ft^2
Spreader - stationary and dumping grate	450,000
Spreader - traveling grate	750,000
Spreader - vibrating grate	400,000
Underfeed - single or double retort	425,000
Underfeed - multiple retort	600,000
Chain grate and traveling grate	500,000

Mechanical stokers generally are classified into three principal groups, which are based on the method of introducing fuel to the furnace:

1. Underfeed stokers
2. Chain-grate and traveling-grate stokers
3. Spreader stokers

The spreader stoker is the most frequently used in the capacity range between 75,000 to 400,000 lb of steam per hour because it responds rapidly to load swings and can burn a wide range of fuels. Underfeed stokers of the single-retort, ram-feed, side-ash-discharge type are used principally for heating and for small industrial units with capacities of less than 30,000 lb of steam per hour. Larger underfeed stokers of the multiple-retort, rear-ash-discharge type have been largely displaced by spreader stokers. Chain- and traveling-grate stokers, while still used in some areas, are gradually being displaced by the spreader and vibrating-grate types.

2.1.1 Stoker Coal Properties

Operators are generally not involved in obtaining coal supply contracts, so they don't need to be experts on all the coal properties. However, the operator is responsible for firing the purchased coal as efficiently and cleanly as possible, and for informing his supervisors of coal related problem areas.

There are several coal properties which have a direct effect on stoker-boiler emissions and efficiency. The operator should be aware of these properties.

Coal Ash--

Coals which are higher in ash content tend to produce higher particulate emissions. This may not always be the case.

The type of ash makes a difference. In recent tests[1] on a traveling grate overfeed stoker a washed coal and an unwashed coal from the same mine were fired in the stoker. The unwashed coal had 10 percent ash, but when washed the same coal had only 4 percent ash. In this case (Figure 2) there was a tremendous difference in particulate loadings because much of the ash in the unwashed coal was a clay-like material which was easily carried out of the furnace by the flue gas.

In tests[2] on other stokers, coals with different ash contents were fired in the same stoker with very little or no change in particulate loading.

Coal Moisture--

Coal has two forms of moisture. First, inherent moisture is a part of the chemical composition of the coal. Second, surface moisture which is due to rain or conditions at the mine. Although the inherent moisture cannot be changed, the surface moisture can sometimes be avoided.

Coal moisture causes two problems. If excessive, it may make the coal hard to ignite, and it will always reduce the boiler efficiency.

Coal Sulfur--

About 95 percent of the sulfur in the coal is converted during combustion to SO_2 and SO_3, commonly called SO_x. The remaining 5 percent is retained in the ash. Therefore, by burning a lower sulfur coal you reduce your sulfur oxide emissions. Of course, there is another reason to burn a low sulfur

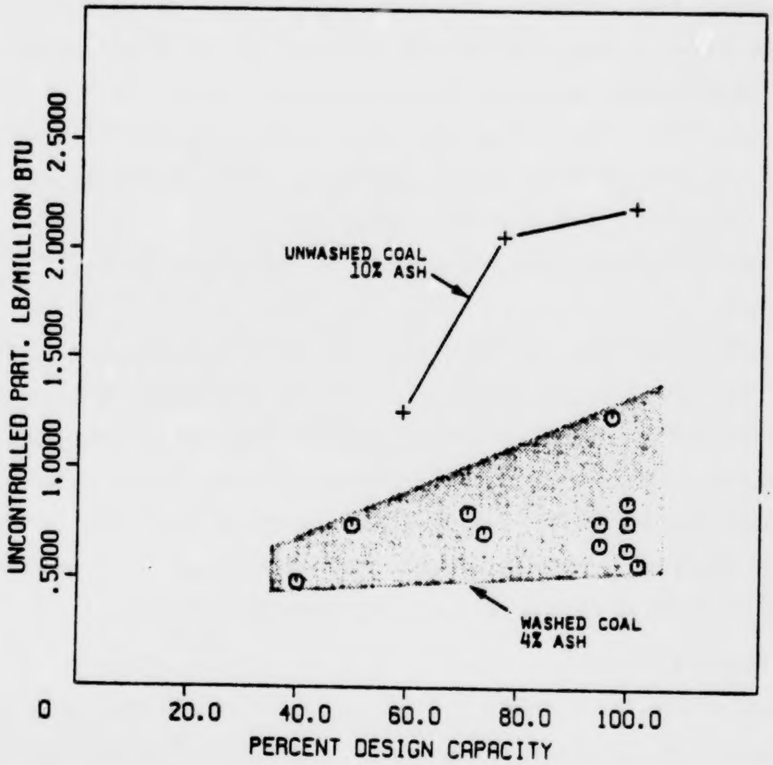


Figure 2. The effect on uncontrolled particulate loading of washing a coal to reduce its ash content (Reference 1).

coal, the sulfur emissions are very corrosive if they condense on exposed metal parts. The SO_3 instantly combines with water vapor (H_2O) to form sulfuric acid (H_2SO_4).

Coal Fines--

The common definition of coal fines is the percentage of coal which passes through a 1/4" screen. Too many coal fines can lead to high particulate loadings because they are easily carried out of the furnace, and high combustible heat losses because the particulate matter carries carbon out of the furnace with it. High fines may also lead to severe clinkering problems.

When firing a high fines coal, make sure that the fines are evenly distributed on the grate, and are not segregated in one area only. The manner in which the coal is loaded into the hopper is important because it may lead to stratification.

A coal which was low in fines when it left the mine may be high in fines when it reaches the furnace because of all the handling it receives. Coals which break up and produce fines more easily than others are called highly "friable" coals. The American Boiler Manufacturers Association has published guidelines for the recommended size consistency of coal for firing in different types of stokers. These are presented in Figures 3, 4, and 5. Every attempt should be made to operate within these guidelines.

Ash Fusion Temperature--

Some coals tend to clinker, slag, and foul the boiler more than others. This is because the ash from these coals becomes sticky and begins to melt at lower temperatures. These coals have low ash fusion temperatures. Clinkering, slagging, and fouling will decrease boiler efficiency by reducing the amount of heat absorbed by the boiler and by increasing the stack gas heat loss. Firing a coal with a lower ash fusion temperature than that for which the boiler was designed can also lead to reduced boiler capacity, and it may require operation of the boiler at a higher and less efficient excess air level.

Free Swelling Index (FSI)--

The free swelling index provides an indication of the caking characteristics of coal when burned on fuel beds. The caking characteristic of coal is the tendency of coal to melt together into a solid mass when rapidly heated.

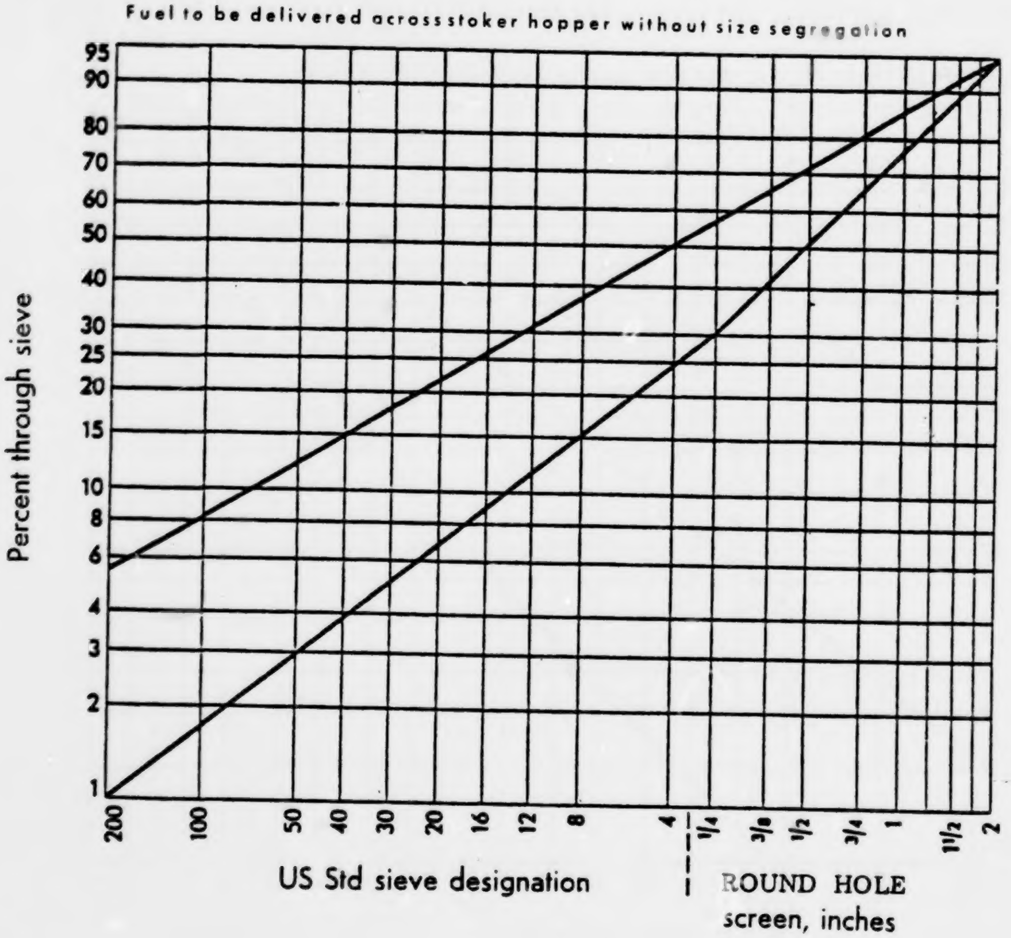
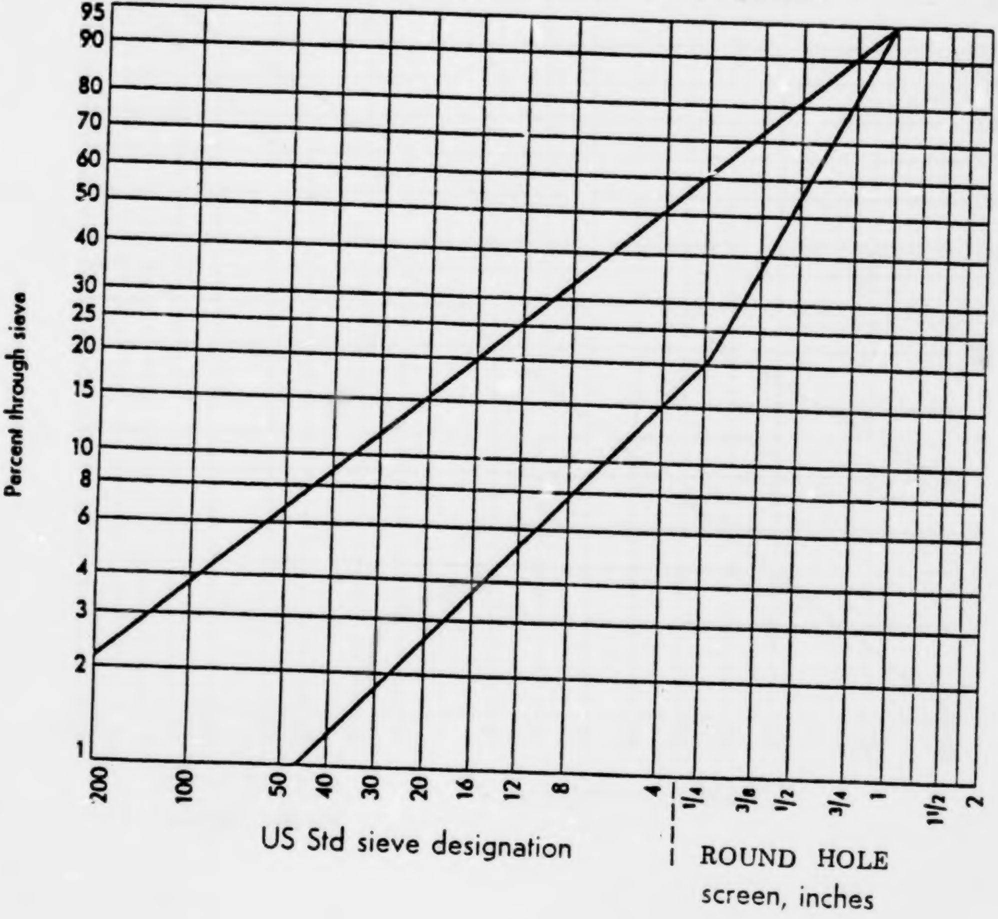


Figure 3. ABMA recommended limits of coal sizing for underfeed stokers.



Size distribution of lower rank coals (Index 28—35) should fall nearer the upper curve, and size distribution of higher rank coals (Index 40—50) should fall nearer the lower curve.

Fuel to be delivered across stoker hopper without size segregation.

Figure 4. ABMA recommended limits of coal sizing for overfeed stokers.

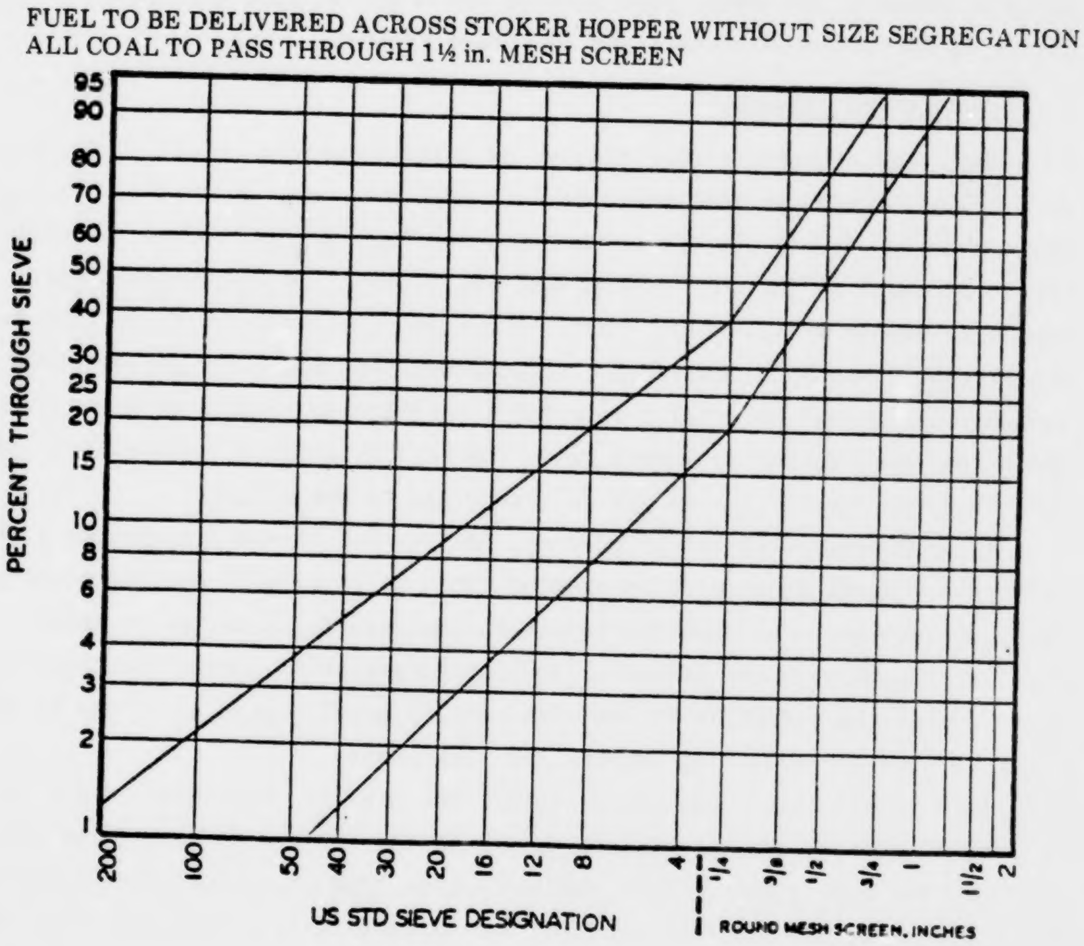


Figure 5. ABMA recommended limits for coal sizing for spreader stokers.

The free swelling index (FSI) is reported on a scale of 1 to 9 in increments of 1/2. Coals having a FSI from 1 to 3 are generally referred to as free burning, from 3½ to 5 as moderately caking, and from 5½ to 9 as strongly caking. Caking characteristics have little or no effect on the performance of spreader stokers. However, free burning and moderately caking coals are preferred for overfeed stokers and underfeed stokers.

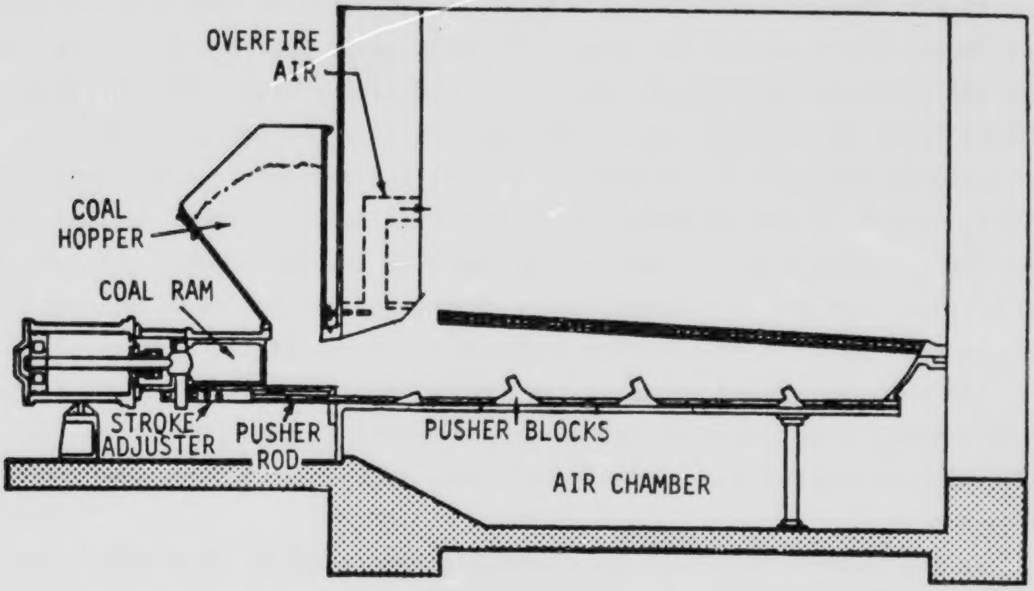
2.1.2 Underfeed Stokers

Underfeed stokers, either single- or multiple-retort, consist essentially of a trough or troughs into which coal is pushed by rams or screws. Part of the combustion air is introduced into the fuel bed through tuyeres or grate bars. Movement of the coal discourages its fusion into large masses that cannot be burned efficiently. Volatile matter is distilled off the coal in these retorts and burns above the incandescent fuel bed. The partly coked and somewhat caked coal then falls into the air-admitting tuyeres or grate bars, where the fixed carbon is burned out. The coal is progressively pushed sidewise or forward until the refuse is discharged to the ashpit.

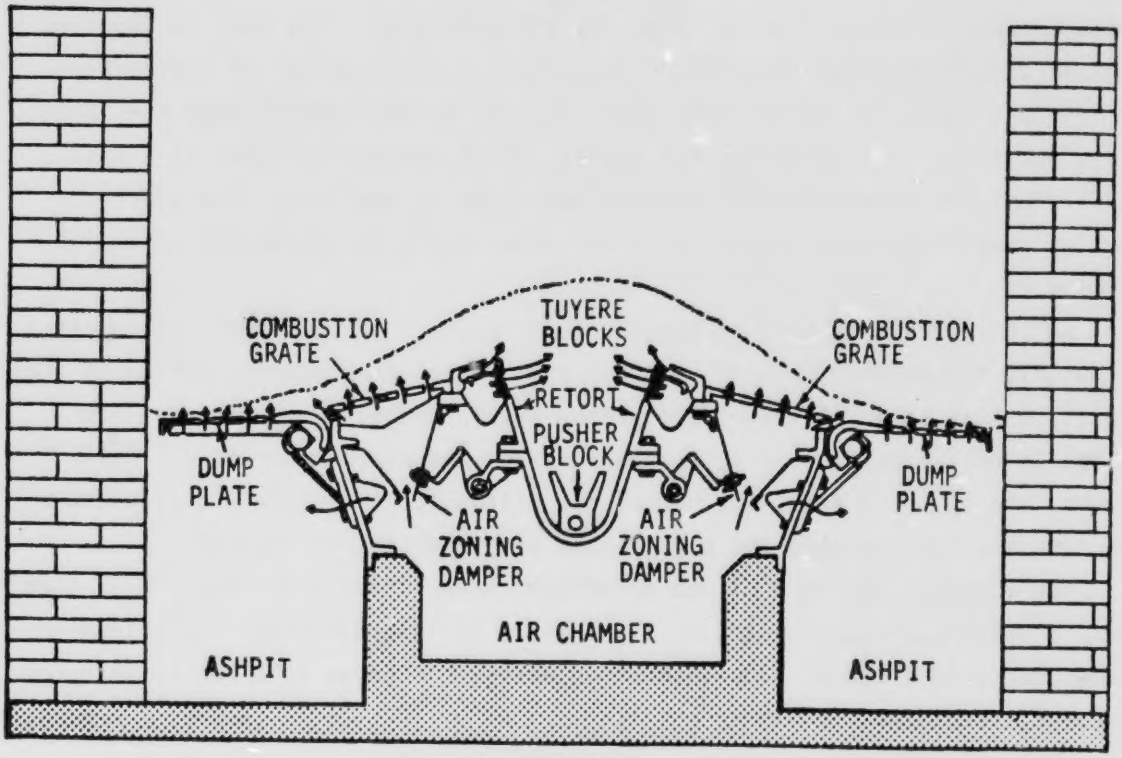
In an underfeed stoker (Figure 6), coal is fed from the hopper to a central retort by means of a reciprocating ram. In very small heating stokers, a screw conveys the coal from the hopper to the retort. A series of small auxiliary pushers in the bottom of the retort assist in moving the coal rearward, and as the retort is filled, the coal is moved upward to spread to each side over the air-admitting tuyeres and side grates.

In a single-retort underfeed stoker, the coal is introduced into a retort; the incoming coal progressively forces the other coal out of the retort and onto the side grates. This feeding action from the retort outward places the entire fuel bed under compression and automatically closes any holes that may tend to form in the bed and thus overcomes a common obstacle to efficient firing.

Ease and simplicity of operation are characteristics of the single-retort stoker. All adjustments are made from the stoker front, and practically all of the fuel bed is visible and accessible through the furnace doors in the stoker front. Cleanout doors provide access to the air chambers under the stoker, so that accumulated siftings may be cleaned out easily.


OVERFIRE AIR
COAL HOPPER
COAL RAM
STROKE ADJUSTER
PUSHER ROD
PUSHER BLOCKS
AIR CHAMBER

SIDE VIEW


COMBUSTION GRATE
TUYERE BLOCKS
COMBUSTION GRATE
RETORT
PUSHER BLOCK
DUMP PLATE
DUMP PLATE
AIR ZONING DAMPER
AIR ZONING DAMPER
AIR CHAMBER
ASHPIT
ASHPIT

END VIEW

Figure 6. Single-retort, horizontal underfeed stoker.

As the coal rises in the retort, it is subjected to heat from the burning fuel above, which ignites the coal. Volatile gases that are distilled off mix with the air supplied through the tuyeres and side grates. The volatile mixture burns as it passes upward through the incandescent zone, and overfire air sustains the ignition of the rising coal and insures complete combustion. Burning continues as the incoming raw coal continually forces the fuel bed to each side. Combustion is completed by the time the bed reaches the side-dumping grates. The ash is intermittently discharged to shallow pits, where it is quenched and then removed through doors at the front of the stoker.

The multiple-retort stoker is an extension of the single-retort stoker. It is nothing more than a series of single-retort stokers built into the same unit, with an appropriate mechanism provided to operate the various components in unison.

In the underfeed section of a multiple-retort stoker fuel bed, parallel rows of hills and valleys of coal extend from the front wall to the discharge ends of the retorts. The hills occur over the relatively inactive retort areas because no provisions are made for air admission. The coal is supplied through a reciprocating feed, which produces a certain amount of segregation in the fuel bed. The coarse coal finds its way to the tuyeres near the front; the fines travel the length of the retort. High combustion rates in a thin active fuel bed occur over the tuyeres where air is admitted. The overfeed section shakes down and levels out these alternately thick and thin parallel ribbons.[3]

As this irregular mass of burning fuel reaches the overfeed section, it is quickly shaken down to uniform thickness by the reciprocating action of the grates in this area. The fuel bed is now level, compact, homogeneous, and extremely active because of the stroke control and correct air feed. As a result, the fuel bed should be burned out uniformly across the stoker width by the time the fuel reaches the dump grates or ash discharge section.

The multiple-retort inclined underfeed stoker is used in many plants that have relatively constant loads or light loads of long duration. This type of stoker can handle these loads without objectionable smoke more easily than the spreader stoker can.

With multiple-retort stokers, overfire-air systems generally have a separate high-pressure fan that develops a pressure of approximately 16 inches

H_2O. This fan is operated intermittently to prevent smoke at low loads or during sudden firing rate increases, which cause distillation of large quantities of volatile gases. Forced draft is supplied to the entire grate area, which is divided into several pressure zones parallel to the retort, each under separate damper control. The air pressure compensates for the thickness of the fuel bed; the greatest pressure is applied to the thickest portion over the retort.

Many small underfeed stokers that handle relatively steady heating loads operate with start-stop control. Stokers that are operated to suit a varying load should be equipped with a modulating combustion control that varies the coal-feed rate and keeps the air supply in step with steam demand. The furnace draft should be controlled through operation of the boiler outlet damper. Primary combustion air is supplied by a forced-draft fan.

2.1.2 Chain-Grate and Traveling-Grate Stokers

The traveling-grate stoker is very versatile for solid fuel burning, and nearly every type of mined fuel can be burned successfully in the various types of stokers. In addition, waste and byproduct fuels such as coke breeze, garbage, and municipal refuse can be burned efficiently and effectively. The traveling-grate stoker has also been used in chemical processes to produce coke and carbon dioxide.

In chain-grate stokers, assembled links, grates, or keys are joined together in an endless belt arrangement that passes over sprockets or return bends at the front and the rear of the furnace. As shown in Figure 7, coal is fed from the hopper onto the moving assembly and enters the furnace after it passes under an adjustable gate that regulates the thickness of the fuel bed. Because the coal flow through the furnace is usually at right angles to the primary air flow, these furnaces are sometimes referred to as crossfeed stoker-fired furnaces. As the layer of coal on the grate enters the furnace, radiation from the furnace gases heats and ignites the coal and the combustible gases that are driven off by distillation. As the fuel bed moves along, it continues to burn and grows progressively thinner. At the far end of its travel, the grate discharges the ash into the ashpit. Although they differ structurally, the operation of chain-grate and other traveling-grate stokers is quite similar.

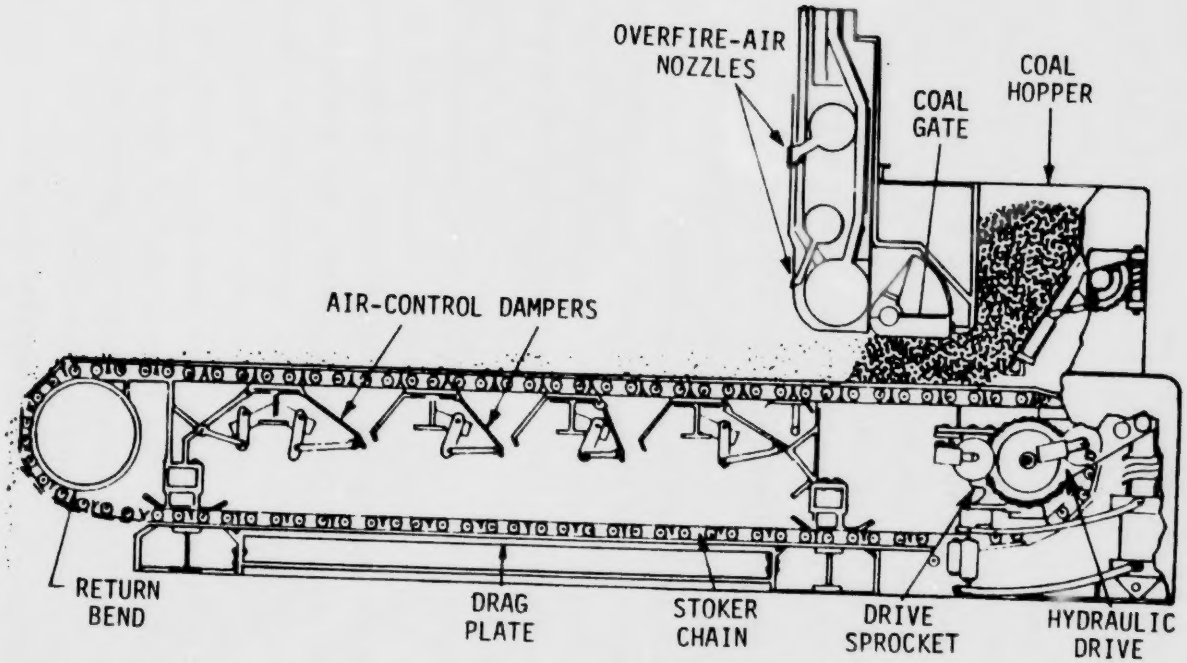

OVERFIRE-AIR NOZZLES
COAL GATE
COAL HOPPER
AIR-CONTROL DAMPERS
RETURN BEND
DRAG PLATE
STOKER CHAIN
DRIVE SPROCKET
HYDRAULIC DRIVE

Figure 7. Chain-grate stoker with rear ash discharge.

2.1.3 Spreader Stokers

Sometimes called overfeed stokers, spreader stokers incorporate the principles of pulverized coal and stoker firing in that fines are burned in suspension and heavier pieces of fuel are burned on the grate. Feeding and distributing mechanisms continually project coal into the furnace above an ignited fuel bed. With this method of firing, coal characteristics have less effect on the fuel bed than they do in other types of stokers. However, fuel characteristics may cause the spreader stoker to smoke if it is operated outside acceptable design ranges. Flash drying of the incoming fuel, rapid release of volatile matter, and suspension burning of the fuel make this method of firing widely applicable. Practically all types of coal have been successfully burned in spreader stokers, as have a wide variety of cellulose fuels, including bagasse, wood chips, bark, hogged wood, sawdust, shavings, coffee grounds, and furfural residue.

Figure 8 shows the principal components of a spreader stoker. As the name implies, the spreader stoker projects the fuel with a uniform spreading action into the furnace above the ignited fuel bed, which permits suspension burning of the fine fuel particles. The heavier pieces that cannot be supported in the gas flow fall to the grate for combustion in a thin fast-burning bed. Compared with other types of stokers, firing is highly responsive to load fluctuations. The almost instantaneous ignition accommodates any increase in the firing rate, and the thin fuel bed can be burned out rapidly if the load suddenly decreases.

Although several different means are available for feeding and distributing coal, the overthrow rotor design is used most widely. Its function is to provide a well-distributed fuel supply at varying rates to match instantaneous increases in loads. A feed plate moves coal from the supply hopper over an adjustable spill plate, from which it falls onto an overthrow rotor equipped with curved blades to provide uniform coal distribution over the furnace area.

The modern spreader stoker installation consists of feeder-distributor units in the widths and numbers required to distribute the fuel uniformly over

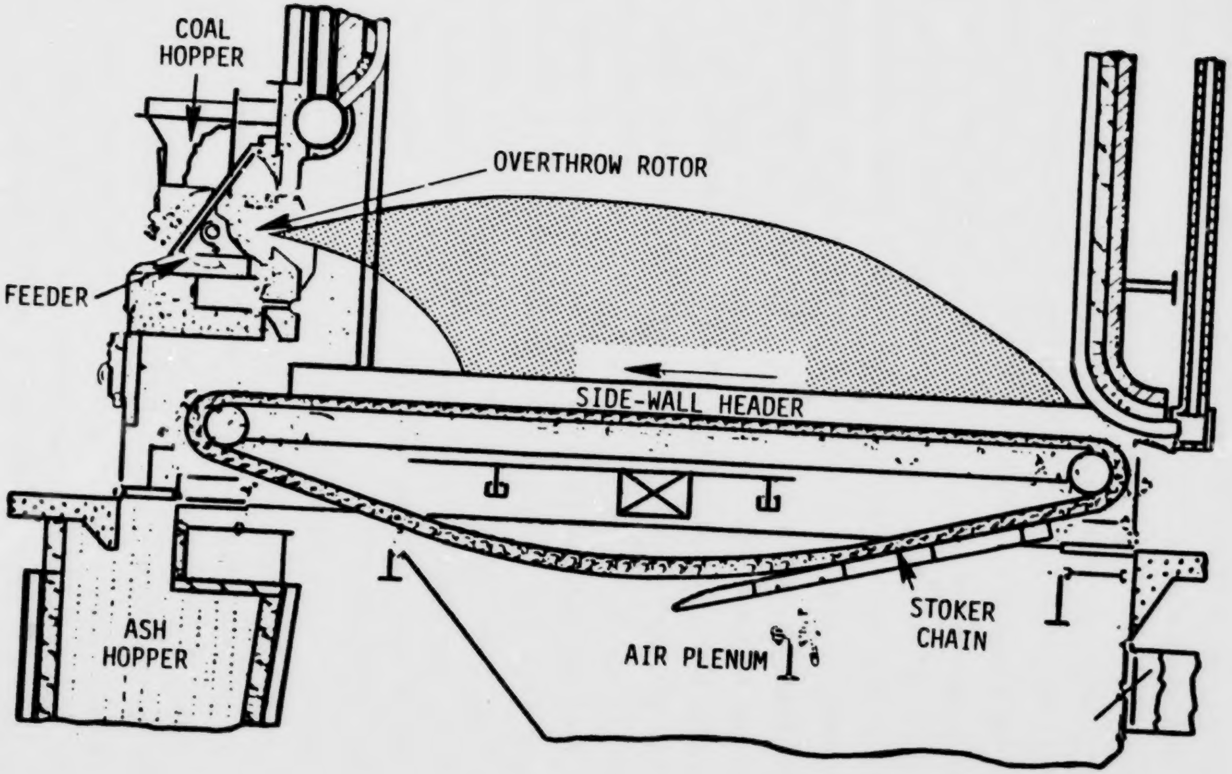

COAL HOPPER
OVERTHROW ROTOR
FEEDER
SIDE-WALL HEADER
ASH HOPPER
STOKER CHAIN
AIR PLENUM

Figure 8. Traveling-grate spreader stoker with front ash discharge.

the width of the grate, specifically designed air-metering grates, forced-draft fans for both undergrate and overfire air, dust collecting and reinjecting equipment, and combustion controls to coordinate fuel and air supply with load demand.

The first spreader-stokers, developed in the early 1930's, used stationary high-resistance air-metering grates, from which the ash was removed manually. This spreader stoker application was limited to boilers with steam capacities below 30,000 lb/h. These stationary grates were soon followed by dumping-grate designs, which provided grate sections for each feeder and correspondingly divided undergrate air plenum chambers. This permitted the temporary shutoff of fuel and air to a grate section for ash removal without affecting other sections of the stoker.

In the late 1930's the continuous-ash-discharge traveling grate of the air-metering design was introduced which brought the spreader stoker into immediate and widespread popularity. The elimination of interruptions for ash removal and the thin, fast-burning fuel bed enabled average burning rates to be increased approximately 70 percent over the stationary- and dumping-grate types. This stoker is generally competitive in sizes up to about 525 ft^2 of grate area, which corresponds to a steam capacity somewhat over 400,000 lb/h.[3] The furnace width required for stokers above this size usually increases boiler costs over those required for pulverized-coal or cyclone units with narrower and higher furnaces.

Although reciprocating and vibrating continuous-cleaning grates also have been developed, the continuous-ash-discharge traveling-grate stoker is preferred for large boilers because of its higher burning rates. For all continuous-ash-discharge spreader stokers, the normal practice is to remove the ashes at the feed end (front) of the stoker. This permits the most satisfactory fuel distribution pattern and provides maximum residence time on the grates for complete combustion of the fuel.

The traveling-grate spreader stoker (Figure 9) has self-adjusting air seals at both the front and rear of the grate. These effectively reduce leakage and stratification of air along the front and rear furnace walls, where it cannot be utilized efficiently in the combustion process.

An overfire air system with pressures from 27 to 30 in. H_2O is essential for successful suspension burning. It is customary to provide at least two

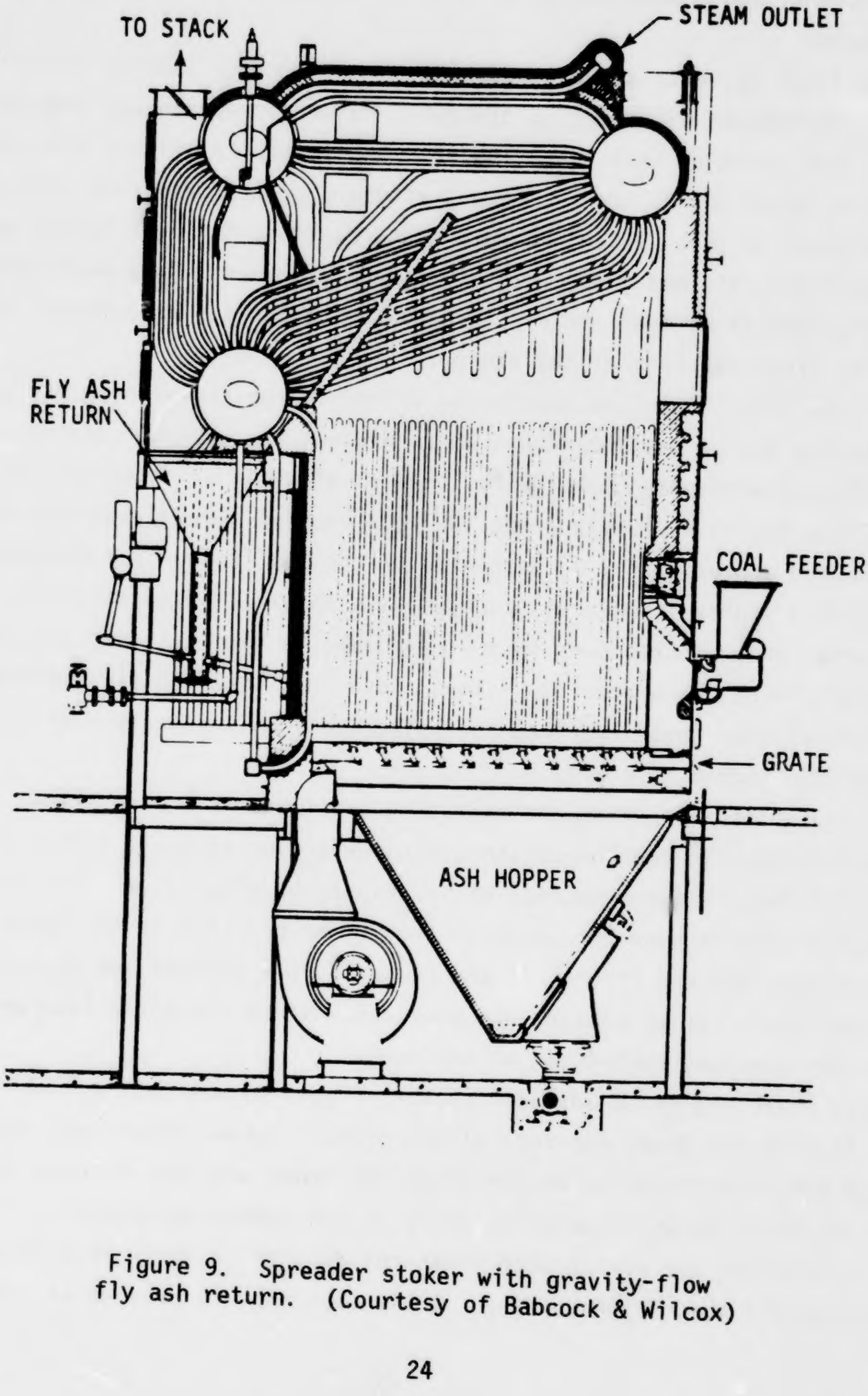

TO STACK
STEAM OUTLET
FLY ASH RETURN
COAL FEEDER
GRATE
ASH HOPPER

Figure 9. Spreader stoker with gravity-flow fly ash return. (Courtesy of Babcock & Wilcox)

rows of evenly spaced high-pressure air jets in the rear wall of the furnace and one row in the front wall (Figure 9). This air mixes with the furnace gases and creates the turbulence required to burn out all of the residual fixed carbon in the fuel and any carbon monoxide that may form.

Fly-Ash Collection and Reinjection Systems--

Because partial suspension burning results in a greater carryover of particulate matter in the flue gas than occurs with other types of stokers, particulate control equipment is required for spreader stokers. Multicyclone collectors are generally used. Fines are deposited in a hopper for discharge to the ash disposal system, and coarse carbon-bearing particles may be skimmed off and returned to the furnace for further burning.[4]

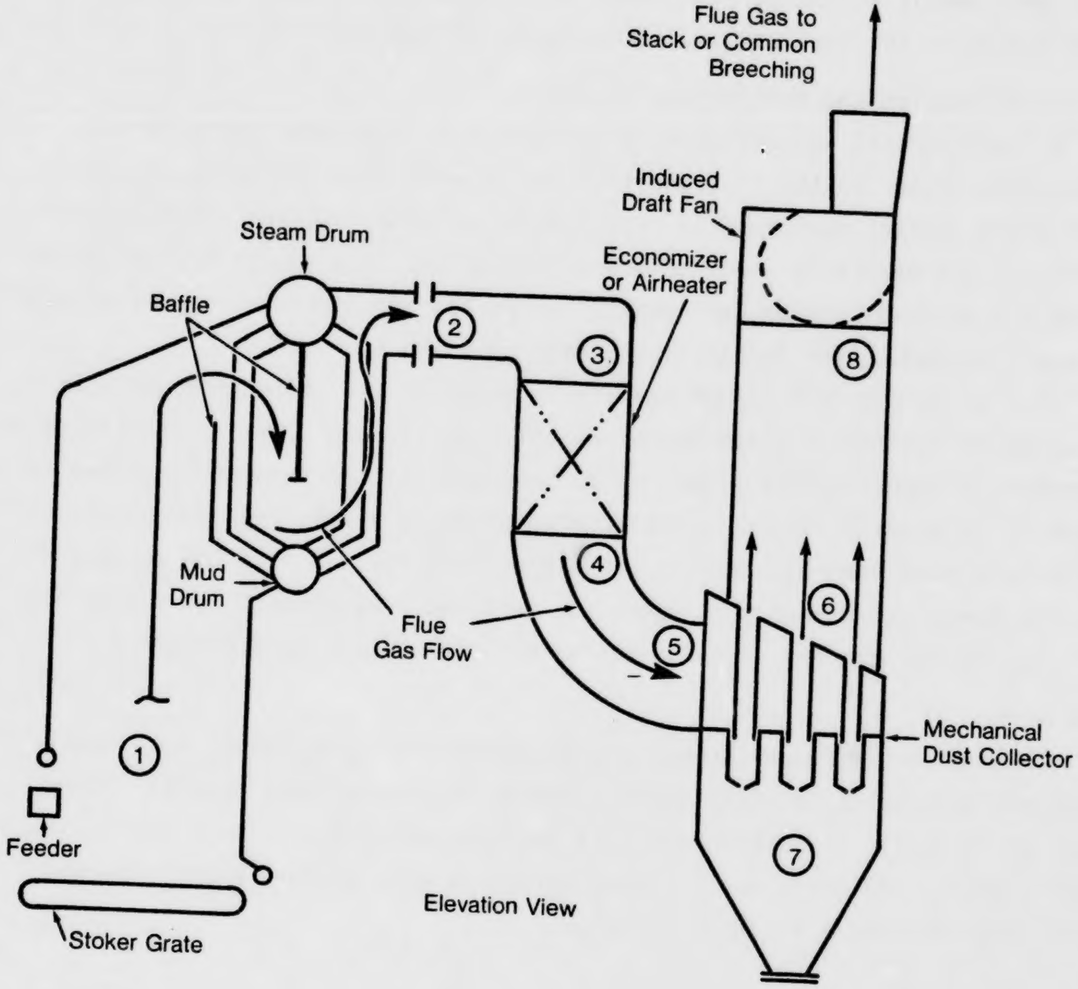
When plant physical layout permits location of the collecting and settling hopper outlets at a sufficient height, the fly ash flows by gravity to a distributing hopper directly behind the rear wall of the furnace, as shown in Figure 9. Pneumatic systems in which high-pressure air is the conveying medium have been used extensively to reinject the fly ash into the furnace in the high-temperature zone just above the fuel bed. Reintroduction of the fly ash into the furnace can increase boiler efficiency by 2 to 3 percent.[4]

Control--

Although the spreader stoker can accommodate varying loads, such loads require close control of fuel and air supply to achieve best results. Many types of automatic combustion controls are available, from simple positioning types used on relatively small installations to more elaborate air-flow and steam-flow regulators in larger plants.

2.1.4 Emissions

Regardless of the type of fuel that is to be burned in underfeed, traveling grate, or spreader stokers, the importance of size segregation cannot be overemphasized. If all the fines are on one side of the stoker and all the coarse coal is on the other, the fines will tend to mat over and the coarse coal will burn rather freely. The resulting maldistribution of air through the fire can cause overheating of the grate surface and other stoker parts. A ragged fire also indicates bad burning characteristics. Figure 10 shows typical static pressure readings in a stoker coal-fired boiler. Thus, the


Flue Gas to
Stack or Common
Breeching
Induced
Draft Fan
Steam Drum
Economizer
or Airheater
Baffle
②
③
⑧
④
⑥
Mud
Drum
Flue
Gas Flow
⑤
Mechanical
Dust Collector
①
Feeder
⑦
Elevation View
Stoker Grate

1. Furnace: —0.15 inches of water
2. Boiler Outlet: —1.20 inches of water
3. Economizer or Airheater Inlet: —1.25 inches of water
4. Economizer or Airheater Outlet: —3.75 inches of water
5. Mechanical Dust Collector Inlet: —3.80 inches of water
6. Mechanical Dust Collector Outlet: —7.30 inches of water
7. Hopper Area of Mechanical Dust Collector: —6.95 inches of water
8. Induced Draft Fan Inlet: —7.35 inches of water

Figure 10. Typical stoker boiler flue gas static pressure.

importance of being sure that the different coal sizes are thoroughly mixed before they are fed to a stoker is apparent.

Overfire air, sometimes referred to as secondary air, is commonly used in furnaces that fire bituminous coal. The overfire air helps to eliminate smoke, and if properly adjusted, improves combustion efficiency. Because turbulent mixing of air and gas is necessary, the air pressure and volume must be sufficient to create the proper turbulence.

The overfire air should range between 5 and 15 percent of the total combustion air requirement. The overfire air requirement is a function of the coal quality and the amount of excess air in the furnace proper. Air at pressures below 6 in. H_2O may not be effective in creating turbulence. At some installations, relatively small quantities of air at pressures up to 25 or 30 in. H_2O are injected to improve combustion conditions in the furnace and to reduce particulate emissions. Air penetration is a function of the static pressure and the volume of air per fuel discharge nozzle, and extreme care must be used in locating and adjusting the overfire air jets.

2.2 PULVERIZED COAL FIRING

Annual consumption of bituminous coal and lignite in the United States is about 500 million tons; more than three-fourths of this amount is used to generate steam. A high percentage of the coal burned for steam generation is in pulverized form, especially in the electric utility industry; however, many large industrial boilers also fire pulverized coal. The main advantage of pulverized coal is that almost any quality of coal can be burned if the boiler is designed properly, because the coal is ground to minus 200 mesh to ensure its combustion.

Experience shows that stoker firing is more economical than pulverized coal firing for units with capacities of less than 100,000 lb of steam per hour[5]; these lower-capacity units can tolerate the lower efficiency of a stoker. In larger plants, where fuel cost is a larger fraction of the operating cost, pulverized-coal firing is generally more economical.

Pulverized Coal Systems--

In a pulverized-coal system, the coal is first pulverized and then delivered to the burners with sufficient air to promote efficient combustion.

The coal feed must be varied rapidly (within specified design limitations) to match load requirements. About 15 to 20 percent of the air required for combustion is used to transport the coal to the burner. This air, known as primary air, also dries the coal in the pulverizer. The remaining 80 to 85 percent of the combustion air, known as secondary air, is introduced at the burner. Figure 11 shows a typical pulverized-coal-fired boiler. The two basic components of a pulverized-coal system are:

- The pulverizer (arranged to operate under pressure or suction), which reduces the coal size to the required fineness.
- The burner, which mixes the pulverized coal and air in the right proportions and delivers the mixture to the furnace for combustion.

Other necessary components are:

- Fan(s) to supply primary air to the pulverizer and to deliver the coal-air mixture to the burner(s).
- Raw-coal feeder, which controls the rate of coal fed to each pulverizer.
- Source (steam or gas air heater) of hot primary air supply to the pulverizer for drying the coal.
- Coal- and air-conveying lines.

Coal must be pulverized until particles are small enough to assure proper combustion, and the surface moisture must be removed from the coal. In the direct-firing system, the coal delivered to the burner is suspended in the primary air; at the burner, the coal and primary air must then be mixed adequately with the secondary air.

Coal and air feed to the pulverizer is controlled by one of two methods: 1) proportioning the coal feed to the load demand and adjusting the primary-air supply to the rate of coal feed, or 2) proportioning the primary air through the pulverizer to the load demand and adjusting the coal feed to the rate of air flow. In either case, a predetermined air-coal ratio is maintained for any given load.

The direct-firing system eliminates the need for storage facilities for pulverized coal and permits the use of high-temperature (~650°F) inlet air to the pulverizer for drying high-moisture coals. A minor disadvantage of the

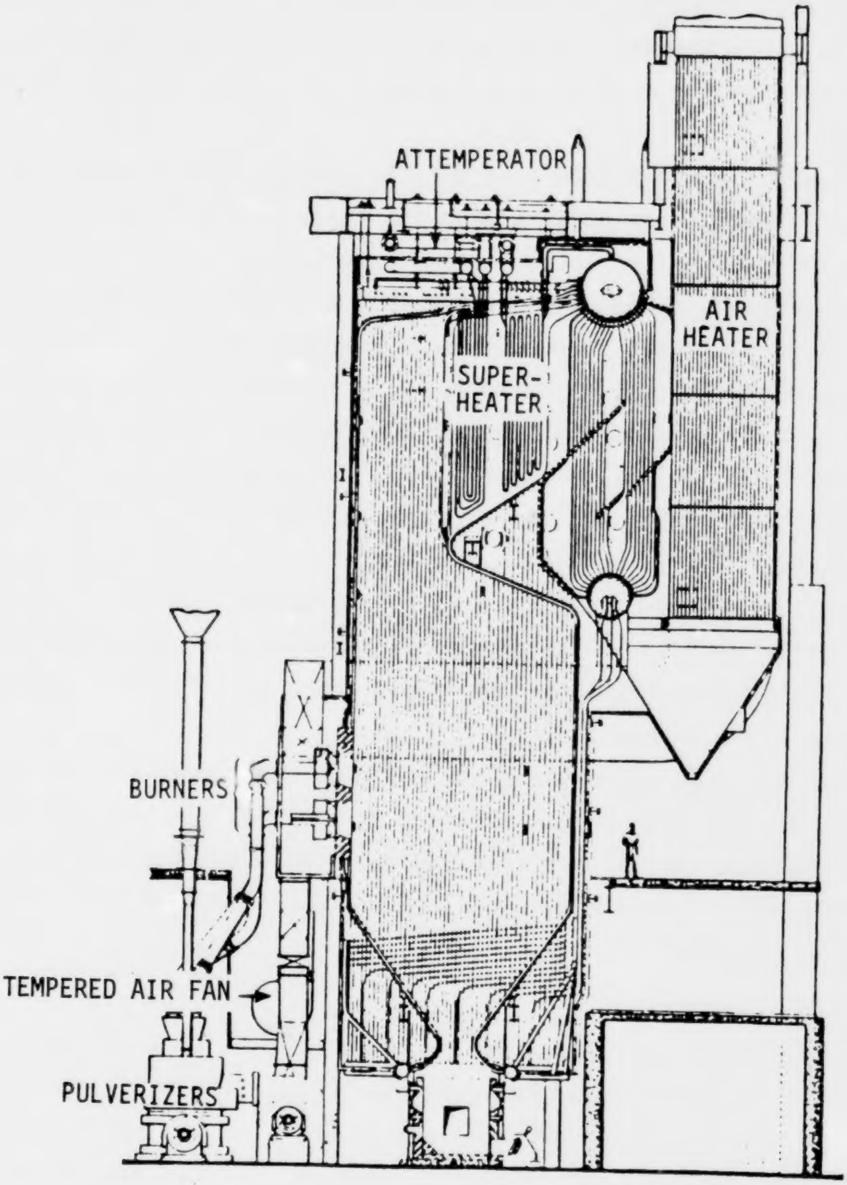

ATTEMPERATOR
AIR HEATER
SUPER-HEATER
BURNERS
TEMPERED AIR FAN
PULVERIZERS

Figure 11. Dry-bottom pulverized-coal-fired unit.
(Courtesy of Babcock & Wilcox)

direct-firing system is that the pulverizer turndown range is usually limited to about 3 to 1 because the air velocities in the lines and other parts of the system must be maintained above the minimum values to keep the coal in suspension. In practice, most boiler units have more than one pulverizer, each of which feeds multiple burners. Load variations beyond 3 to 1 are generally accommodated by shutting down or starting up a pulverizer and the burners that it supplies.

Idle burners are subject to considerable radiant heat from the furnace and can attain temperatures above the coking temperatures of the coals. The use of alloy metals provides longer life for burner parts; however, if these parts are not adequately cooled below the coking temperature before being placed in service, coke may form and severely damage them. The easiest way to cool the fuel discharge nozzles is to run cold primary air through the pulverizer and burners for 5 to 10 minutes and then immediately feed the coal before the nozzles can reheat. Because there is no simple way to cool selected burners on a single pulverizer before bringing them into service, a pulverizer and all its burners should be operated at once.

Large boilers with air heaters have a sizable heat inertia, and at full load, it requires upward of 6 hours for temperatures throughout the unit to stabilize. A significant time period is also necessary for such boilers to re-equilibrate after a load change.

The temperature of the primary air entering the pulverizer may run 650°F or more, depending on the surface moisture of the coal and the type of pulverizer. Coal grinding to a fineness of 200 mesh (90 percent) is necessary to assure maximum efficiency and to minimize the deposit of ash and carbon on the heat-absorbing surfaces.

Exhausters and Blowers--

If the pulverizer operates under pressure, the primary-air fan handles clean air and is not abraded by the pulverized coal. In this case, a high-efficiency fan with an efficient rotor design and high tip speed can be used. If the pulverizer operates under suction, however, the fan must handle pulverized-coal-laden air. This requires that the fan housing be designed to withstand a potential explosion pressure of 200 psi within the fan to comply with National Fire Protection Association requirements. Furthermore, because the fan is subject to excessive wear, its design is limited to heavy paddlewheel construction and hard-metal or other protective-surface coatings. All of these construction features are detrimental to the fan's mechanical efficiency.

Standards of Burner Performance--

Operators of pulverized-coal equipment should expect burner performance to meet the following conditions:

1. The coal feed and air supply should match the load demand over a predetermined operating range. For most applications, ignition of the pulverized coal must be stable without the use of supporting fuel over a load range of approximately 3 to 1. Most steam boilers are equipped with several pulverizers so that a wider capacity range can be readily obtained by varying the number of burners and pulverizers in use.
2. Unburned combustible loss should be less than 2 percent. With most well-designed installations it is possible to keep the unburned combustible loss under 1 percent with excess air in the range of 15 to 22 percent, measured at the furnace outlet. This loss is a good indication of burner condition and pulverizer condition. Coal fineness and carbon should be checked daily.
3. Adjustments to the burner should not be necessary to maintain flame shape. The design should be such that formation of deposits are avoided that could interfere with continued efficient and reliable burner performance over the operating range.
4. Only minor repairs should be necessary during the annual overhaul. Burner parts subject to abrasion may require more frequent replacement. Alloy steel should be used for parts that cannot be protected by cooling or other means to avoid damage from high temperatures.
5. Safety must be paramount under all operating conditions.

Ignition Stability--

For ignition stability, the temperatures of the primary air and coal leaving the pulverizer must be at least 130°F for units burning coal with more than 30 percent volatile matter; temperatures up to 180°F may be required if the volatile matter of the coal is as low as 22 percent. For coals with at least 25 percent volatile matter, the maximum temperature of the primary air-coal mixture leaving the pulverizer is approximately 150°F; higher temperatures increase the tendency for coking on the burner parts.

Modern Burner Types--

Intervane burners are the most commonly found burner in industrial coal-fired boilers. Circular and cell type burners also are used. Figures 12, 13, and 14 show typical burners that fire pulverized coal. Burners are available that fire pulverized coal, oil, gas, or any combination of these three fuels; however, the firing of pulverized-coal combined with oil in the same burner should be restricted to short emergency periods. It is not recommended for long operating periods because of possible coke formation in the burner. Usually, the maximum heat input per burner is about 165 million Btu per hour. At full boiler load the secondary-air port velocity ranges from 4000 fpm for small boilers, where unheated secondary air is used, to 6000 fpm for a dry-ash-removal furnace with 600°F air. Velocities of 7500 fpm are common with circular burners in slag-tap furnaces.

Lighters (Ignitors) and Pilots--

Although ignition and control equipment for pulverized-coal firing is similar to that for oil and gas, it is used differently. In pulverized-coal applications, ignitors must be kept operating for hours, until the temperature in the combustion zone is high enough to assure self-sustaining ignition of the main fuel.

The self-igniting characteristics of pulverized coal vary from one fuel to another, but for most coals ignition can be maintained without auxiliary fuel down to about one-third of the burner capacity. When the pulverized coal being fired has less than 25 percent volatile matter, it may be necessary to activate the ignitors even at high loads. This particularly applies to coal that is wet or frozen or when coal feed to the pulverizers is disrupted. If the ignitor is not activated when the coal feed to the pulverizer is interrupted, ignition may be lost momentarily; when the coal flow is reestablished, an adjacent burner may reignite the burner with explosive force and damage the burner and/or the boiler.

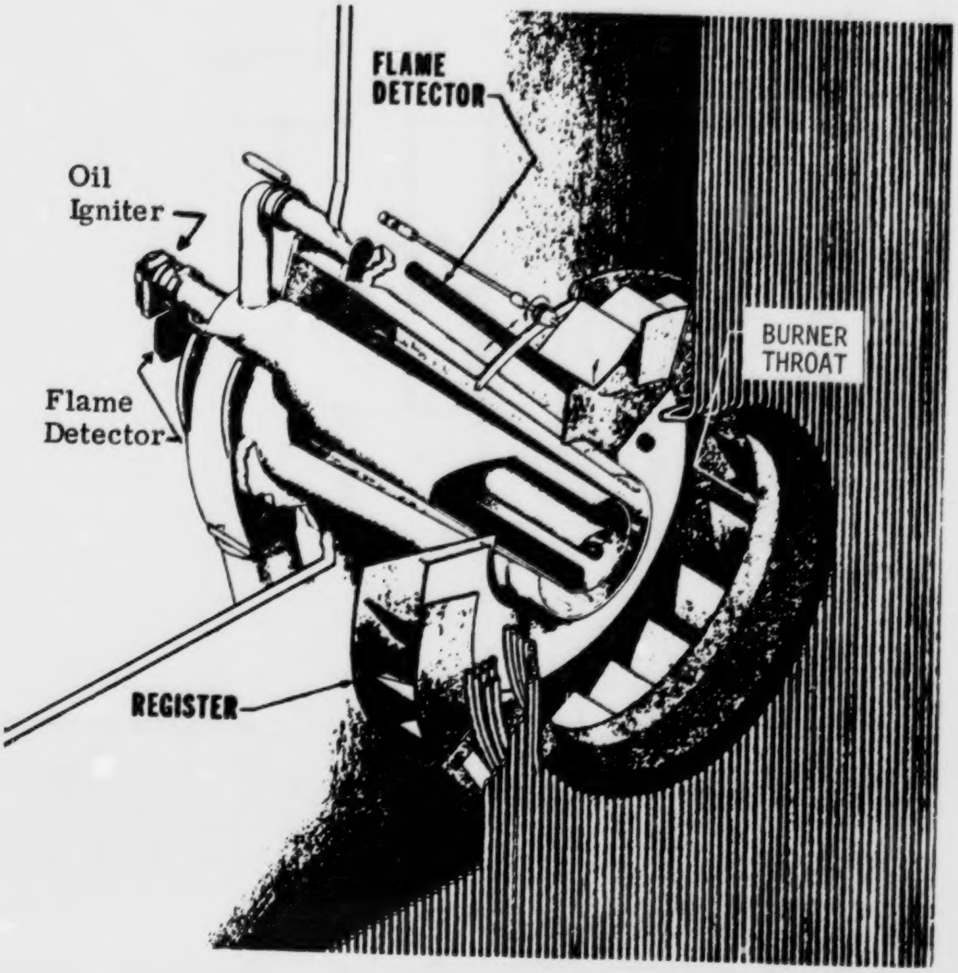

FLAME DETECTOR
Oil Igniter
BURNER THROAT
Flame Detector
REGISTER

Figure 12. Intervane burner.

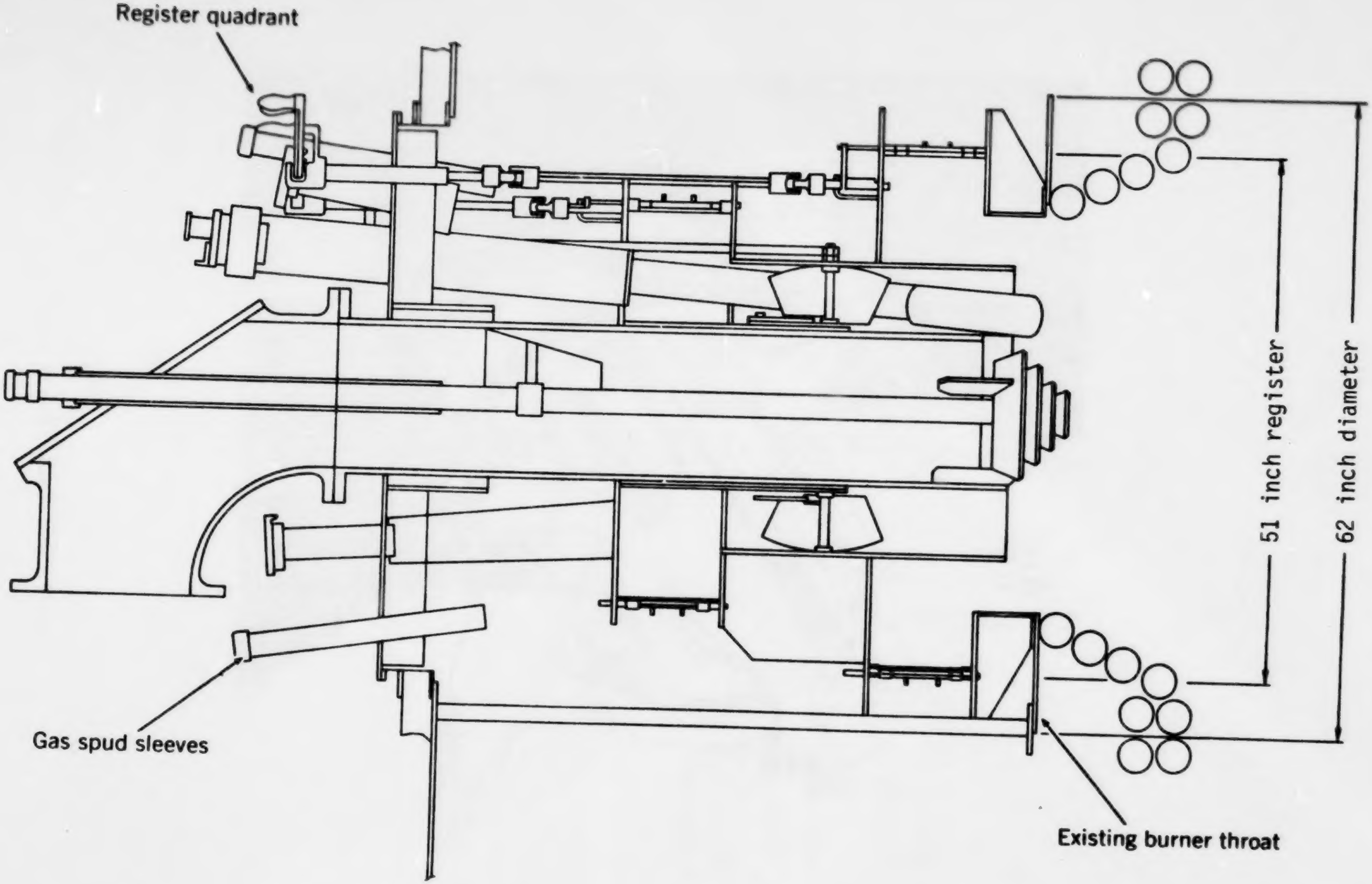

Register quadrant
Gas spud sleeves
51 inch register
62 inch diameter
Existing burner throat

Figure 13. Dual-register field-test burner.

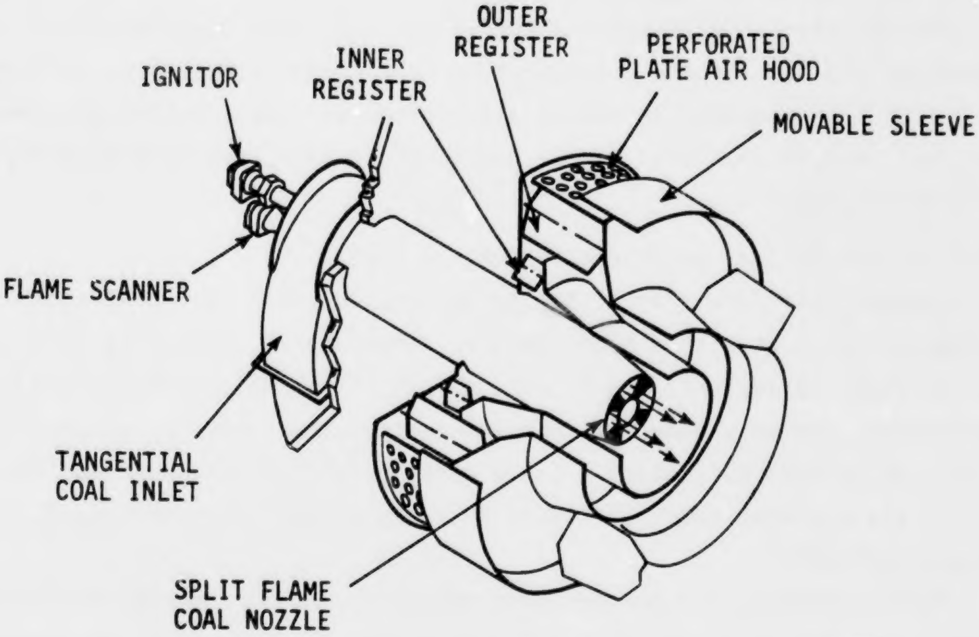

OUTER REGISTER
INNER REGISTER
PERFORATED PLATE AIR HOOD
IGNITOR
MOVABLE SLEEVE
FLAME SCANNER
TANGENTIAL COAL INLET
SPLIT FLAME COAL NOZZLE

Figure 14. Components and functions of a controlled-flow/split-flame coal burner.

Excess Air--

More excess air is required for satisfactory combustion of pulverized coal than for oil or natural gas. One reason for this is the inherent maldistribution of coal to individual burner pipes and to the fuel discharge nozzles. At high loads, the minimum acceptable quantity of unburned combustible matter usually requires about 15 percent excess air at the furnace outlet. This allows for the normal maldistribution of primary air, secondary air, and coal. Higher excess air values may be necessary to avoid slagging or fouling of the heat absorption equipment.

The designer of a pulverized-coal-fired unit must consider the burner arrangment and the furnace configuration to minimize slagging or fouling of the boiler. An increase in excess air will permit satisfactory performance with most designs, but this may be uneconomical as a long-term substitute for good basic design.

Starting Cold Boilers and Operating at Low Loads--

Because coal is difficult to ignite, any unburned fuel that escapes on startup is dry dust with a high ignition temperature. This dust does not readily cling to surfaces and is carried out of the unit with the products of combustion. The only potential problem is that this dust can accumulate in hoppers or in dust collectors. These containers should be emptied frequently so that the unburned material cannot build up to the point that it ignites and damages equipment.

During startup, oil burners with mechanical atomizers can be used to sustain ignition of pulverized coal with little risk of air-heater fires. Only a small amount of oil is used, and the resulting deposits are generally inconsequential.

Coal-fired boilers produce significant quantities of particulate matter, SO_2, and NO_x. The level of each of these pollutants is related to the firing method, the combustion efficiency, the pollution-control equipment, and the fuel characteristics.

The quantity of SO_2 produced is nearly proportional to the coal sulfur content, but the pulverizers directly reject some pyritic sulfur (usually not more than about 5 percent of the total coal sulfur content). Because sulfur affects the ash fusion temperature, the coal sulfur content affects boiler design and operating characteristics.

The generation of NO_x is strongly related to the combustion method and combustion controls. Free nitrogen in the coal tends to be a significant contributor to overall NO_x emissions. Most NO_x controls deal with the adjustment of combustion air to the burners of pulverized-coal-fired boilers. Staged combustion or off-stoichiometric firing produces lower peak flame temperatures by limiting the amount of air available for combustion. This generally produces long diffusion-limited flames and thus provides longer reaction times at lower temperatures for complete combustion. Excess air, usually 15 to 30 percent, is gradually introduced to the flame. The minimum attainable NO_x emissions are generally dictated by the nitrogen content of the fuel. Tangential or corner-fired pulverized-coal-fired boilers tend to produce less NO_x than wall-fired units.

The particulate emission rate is a function of the coal ash content and the firing method. Pulverized-coal-fired boilers emit between 70 and 85 percent of the ash in the coal as fly ash. In contrast, a stoker-fired boiler emits only 30 to 50 percent of the coal ash with the flue gas. In addition, the particulate matter generated by stoker boilers tends to be much coarser than the ash from pulverized-coal-fired boilers, and it generally contains considerably more carbon. These factors affect the selection of control equipment for specific boilers.

Malfunctions--

Although numerous boiler malfunctions can occur, the two most common operational problems result from inferior fuel quality and the use of improper excess air levels. The selected excess air levels are often much higher than necessary for complete combustion, which decreases boiler efficiency and increases the amount of fuel required to develop a given quantity of steam. Too much excess air can also increase emissions.

The nitrogen and oxygen in the excess air produce a dilution effect. Although the peak flame temperature may increase with excess air, the average flame temperature decreases as a result of the dilution. This decrease in average temperature reduces the radiant heat transfer to the furnace walls, and in extreme cases, the extra gas volume may carry unburned fuel out of the furnace zone.

The volume of excess air increases the velocity of the flue gas through the convective tube passes because the volume between the tubes is fixed.

This velocity increase improves the heat transfer rate in the convective section slightly, but the improved heat transfer rate fails to offset the corresponding decrease in heat transfer in the radiant zone described earlier. Thus, excess air effects a net heat transfer loss. The usual indicators are increases in the temperature and in the oxygen (O_2) concentration at the stack.

Proper excess air levels range from 20 to 30 percent for pulverized-coal-fired boilers. The excess air level for best boiler efficiency is generally one that produces a very low carbon monoxide (CO) concentration. Boiler excess air can be monitored via CO_2 or O_2 monitors at the outlet of the radiant heat zone. Typically, CO levels are maintained at approximately 100 ppm, and maximum levels of 400 ppm are usually established to preclude explosions resulting from CO pockets within the boiler.

The symptoms of sootblower failure are the same as those for high excess air. Sootblowers use steam or compressed air to clean deposits from the boiler tubes. The ash load and ash properties dictate sootblowing requirements. Continuous sootblowing may be required for some pulverized-coal-fired boilers. Failure to blow the soot from the boiler tubes allows deposits to form, which reduce the heat transfer rate through the tubes. The resulting decrease in efficiency is characterized by an increase in stack temperature; O_2 and CO_2 levels are unaffected.

Coal sizing is not a big problem for pulverizers; the maximum allowable top size for most pulverizers is about 2 inches. Very high quantities of fines may cause problems in some pulverizers, but most are easily capable of producing the required fineness (70 to 75 percent through a 200-mesh screen).

Most pulverized-coal-fired boilers have at least one extra pulverizer to allow routine maintenance to be performed without reducing the boiler load. Selection of the number of pulverizers needed to handle the desired load is based on the heat content and grindability of the coal because these characteristics affect pulverizer capacity. Because pulverizers are expensive, excess capacity is held to a minimum. If the grindability of the coal decreases (making it more difficult to grind) or if the heat content of the coal decreases, existing pulverizers may not be sufficient to maintain the necessary steam rate.

Changes in the ash content and other characteristics of the coal can significantly affect boiler operation. A high-ash coal can increase the sootblowing requirement or increase heat losses as a result of impaired heat transfer. A more serious problem is an increase in the slagging potential of the ash. This can necessitate derating the boiler to prevent slagging. A sticky ash coating that reduces heat transfer efficiency can make boiler operating conditions difficult to control. Sticky ashes can be hard to remove, and they may form localized hot spots, which damage the boiler tubes. Coal blending sometimes leads to similar problems as a result of the formation of eutectic ash from the blended coal. This ash has a lower fusion temperature than the ash for either coal by itself.

Improvement in coal quality can also lead to operating problems in a pulverized-coal-fired boiler. If a nonslagging coal is burned in a boiler designed for a slagging coal, furnace walls may be too clean, and too much radiant heat may be absorbed, which makes it difficult for the superheater to produce the necessary steam temperatures. A reduction in sootblowing can alleviate this problem.

Fineness of the coal from the pulverizers should be checked frequently. Failure to feed coal of requisite fineness to the burners may impair combustion and thereby allow carbon carryover to the control equipment, which causes inefficient boiler operation. Excessively fine pulverization wastes energy and reduces pulverizer capacity. If Eastern bituminous coal is burned, 70 to 75 percent of the coal should pass through a 200-mesh screen. Somewhat less fineness (60 to 65 percent) is necessary with Western subbituminous coal because of the noncaking properties of this coal.

A tube leak eventually causes boiler shutdown and also affects control equipment operation. Waterwall, boiler tube, and economizer tube leaks have the greatest effects on control equipment operation. Significant quantities of water can escape into the flue gas, plug multicyclones and fabric filters, and make ash removal from electrostatic precipitator (ESP) plates difficult.

Freezing conditions can affect coal flow to the boilers. The coal can hang up in chutes, hoppers, feeders, or even railcars. In stoker boilers, frozen fuel can cause underfire air to channel to uncovered portions of the grate, which reduces the underfire air to other portions of the grate. This can cause distortion of the grates, as both the ash layer and the underfire air help to protect the grates. In addition, the channeling of the air changes local excess air conditions and increases emissions.

2.3 FANS

The gas flow rate is a key parameter in the evaluation of the performance of any pollution control system. The inspector should rely on current pitot tube measurements to determine the flow rate of the pollution control system.

In some cases, fan data can be used to estimate the gas flow during the inspection. Using a published fan curve, the inspector should correct all readings to standard conditions and determine the gas flow in standard cubic feet per minute. An estimate made in this manner is subject to errors because of the variability in fan performance, fan modifications that may have been made, and the mechanical condition of the fan. If a fan curve is not available, the inspector can use the F-factor method (discussed in Section 2.4) to estimate flue gas and fuel rates.

Fan data can be used to diagnose changes that have occurred since the last previous inspection. In many cases, however, baseline data are not available because fan parameters are not routinely measured during conventional inspections. A radial-blade centrifugal fan is typically used for dirty gas service. Operating characteristics are illustrated by the curve in Figure 15, which applies to a New York Blower Company size 332 general industrial fan with an LSD wheel operating at 1460 rpm at standard conditions. Static pressure losses in the control equipment and ductwork (curve A) are proportional to the square of the flow rate. The fan develops less static pressure at higher flow rates, however; thus it has a strong negative slope (curve B). The intersection of the system line and the fan pressure drop curves defines the operating point of the system. At this point, the gas flow rate is 8,400 scfm (approximately 40,000 lb steam/h boiler), and the brake horsepower (curve C) is approximately 24.5.

A major problem with boilers is that as they get older they tend to lose capacity because the fan cannot accommodate increases in excess air, inleakage, and general system deterioration (such as fabric filter blinding, increases in ductwork friction, etc.). A reduction in boiler load is usually required to compensate for this, but plants sometimes replace the fan drive sheaves to speed up the fan. The latter is not always a feasible remedy.

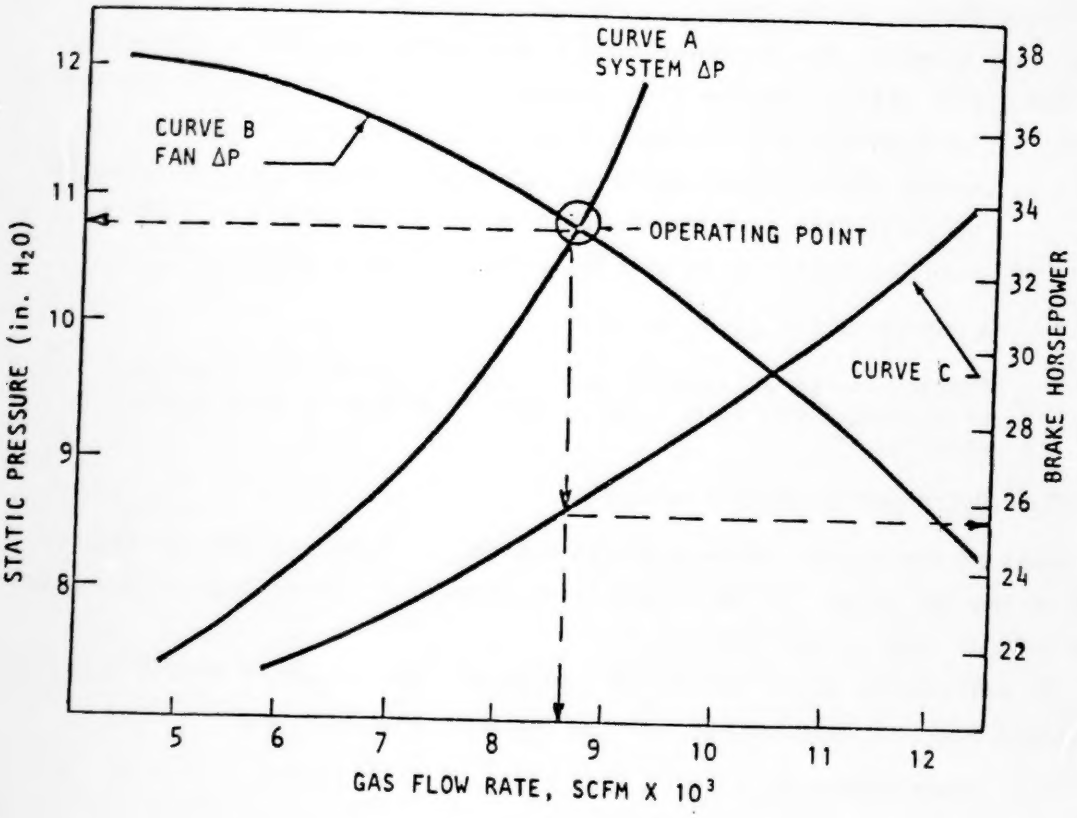


Figure 15. Operating characteristics of radial-blade centrifugal fan (New York blower size 332 with LSD wheel at 1460 rpm).

Effects of fan speed on operating characteristics are shown by the curves in Figure 16. In Case 1, a speed increase leads to a greater gas flow rate and higher static pressure. Increasing the fan speed may be a feasible course of action at plants where the boiler gas flow is insufficient; however, the fan must be operated within its acceptable published range of speeds. Increased flows can adversely affect fabric filters or ESP's. On the other hand, a decrease in fan speed (perhaps to save energy) decreases the flow substantially; Case 2 shows such reduced gas flow. A decrease in fan speed can reduce the collection efficiency of cyclones and wet scrubbers because these control devices depend on gas velocity for particle collection.

Other changes in fan operation may occur without the operator's knowledge. For example, the fan motor current may either increase or decrease when the system static pressure drop increases; Case 3 in Figure 17 represents a total system pressure drop increase from the baseline condition. An increase in the fan motor current would accompany this change, as indicated in Table 2. The static pressure increase may be due to a variety of factors. Static pressure decreases can be caused by the following factors:

- A change in the gas flow rate.
- Changes in operating conditions such as control device short-circuiting (open access doors, gaps in ductwork, open by-pass dampers).
- Decreased scrubber liquor flow.

The cause of the change can be analyzed further by measuring the gas temperature at the fan inlet. A low temperature suggests either an open access hatch or a serious leak in the ductwork.

In addition to analyzing the fan operation, the inspector should visually check the physical condition of the fan and note the following:

- Blade abrasion
- Deposits
- Corrosion of the wheel and fan housing.

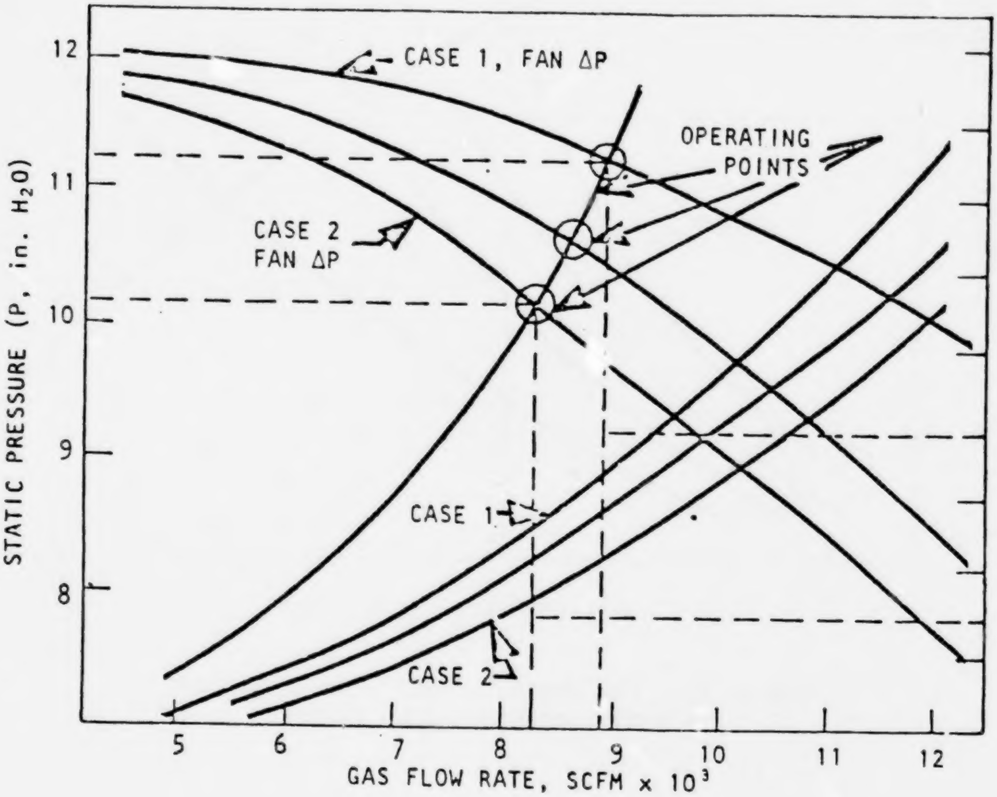


Figure 16. Fan characteristic curves--effect of speed change.

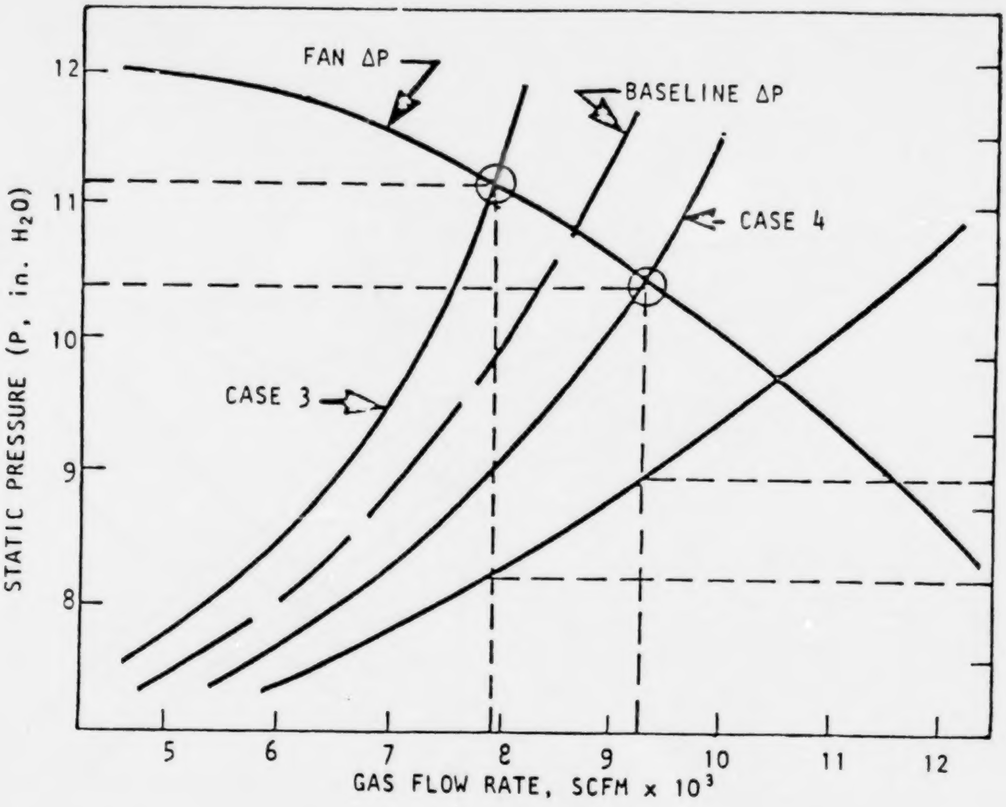


Figure 17. Fan characteristic curves--effect of system pressure drop change.

TABLE 2. INTERPRETATION OF FAN OPERATING CONDITIONS (RADIAL-BLADE TYPE ONLY) SHOWN ON FIGURES 15 AND 16.

Case	Fan parameters			Possible causes
	Calculated ΔP_{sp} at 70°F	Calculated amps at 70°F	Fan speed, rpm	
1	Decreased	Decreased	Decreased	Fan speed increase (sheave change or belts tightened)
2	Increased	Increased	Increased	Fan speed decrease (sheave change or loose belts)
3	Increased	Decreased	Unchanged	a) Filter blinding b) Filter cleaning problem c) Hopper overflow d) Scrubber bed plugged e) Decreased gas flow f) Reset damper
4	Decreased	Increased	Unchanged	a) Baghouse leaks b) Shortcircuiting c) Decrease in liquor flow d) Increase in gas flow e) Reset damper

The inspector should be sure to lock the fan out of service before attempting to conduct a physical inspection.

Blade abrasion and deposits indicate excess emissions of large particles (10μm) and suggest a particulate control device malfunction. Fan operating parameters indicate a number of important changes in control device operating conditions. For an estimate of actual flow rates, the certified rating curve for the fan must be corrected to the gas temperature at the fan inlet by using the factors in Table 3.

Generally, if the fan operating parameters (static pressure, motor current, fan speed) are within 10 percent of the baseline condition and if the gas temperature at the fan inlet is within 20°F, it is unlikely that gas flow changes have caused mass emissions to change significantly from baseline conditions.

TABLE 3. FAN DATA, TEMPERATURE CORRECTION.[a]

Temp	Factor	Temp	Factor	Temp	Factor
20	0.91	220	1.28	420	1.66
40	0.94	240	1.32	440	1.70
60	0.98	260	1.36	460	1.74
80	1.92	280	1.40	480	1.77
100	1.06	300	1.43	500	1.81
120	1.09	320	1.47	520	1.85
140	1.13	340	1.51	540	1.89
160	1.17	360	1.55	560	1.92
180	1.21	380	1.59	580	1.96
200	1.25	400	1.62	600	2.00

[a] The published flow rate from the fan curve is multiplied by the above factors to estimates actual flow at fan inlet temperature. Adapted from "Basic Energy/Environment Analysis," NAPA Information Series 67, by C. Heath, August 1978.

2.4 USE OF THE F-FACTOR

Stack sampling teams have used the F-factor as an accepted method of obtaining heat input of combustion sources through measurement of gas velocity and gas conditions for the purpose of determining gas volume. During inspections of combustion sources, inspectors often find that both the heat input and gas conditions are determinable but the gas volume is the unknown factor. The F-factor method is used to ascertain the missing value needed for the evaluation of control equipment performance.

The simplest case is one in which both wet and dry F-factors (F_w and F_d) are available for a known fuel. The oxygen content is usually determined on a dry basis; thus, an equation relating gas volume, temperature, and moisture may be written:

$$Q = \text{heat input rate} \times \left[\left(F_d \times \begin{matrix}\text{stack oxygen}\\ \text{correction}\end{matrix}\right) + (F_w - F_d)\right] \times \begin{matrix}\text{temperature}\\ \text{correction}\end{matrix} \qquad (1)$$

where Q = gas flow rate, acfm;

Stack oxygen correction factor = $\frac{20.9}{20.9 - \%O_2}$; and

Temperature correction factor = $\frac{°F + 460}{528}$

EXAMPLE -- Heat input rate = 100 x 10^6 Btu/h (using bituminous coal) or
1.667 x 10^6 Btu/min

F_d = 9,820 dscf/10^6 Btu

F_w = 10,680 wscf/10^6 Btu

Temperature = 350°F

Oxygen content = 5.0%

$$Q = 1.667 \times [9{,}820 \times (\frac{20.9}{20.9 - 5.0}) + (10{,}680 - 9{,}820)] \times \frac{350 + 460}{528}$$

$$= 1.667\ (12{,}908 + 860) \times \frac{810}{528}$$

$$= 1.667\ (13{,}768)(1.53)$$

$$= 35{,}210 \text{ acfm at } 350°\text{F}.$$

The term (F_w - F_d) accounts for water produced during the combustion process and assumes that excess fuel moisture does not significantly affect the values for F_w. For fuels where moisture content is significant and may be variable, however, the above formula is usually not applicable. When this is the case, utilization of a fuel moisture correction factor is usually required. This is particularly true in the firing of wood or bark, in which the moisture content may be as much as 50 percent of the fuel weight. If the weight percent of the water in the fuel is known the equation would be:

$$Q = \text{heat input rate} \times [(F_d \times \text{stack oxygen correction}) + \frac{\%H_2O \text{ (in fuel, wt.)} \times 21.41}{1 - \%H_2O \times 10^6 \text{ Btu/lb fuel, dry}} + (F_w - F_d)] \times \text{temperature correction.} \quad (2)$$

This formula accounts for the vaporization of the moisture in the fuel as well as the formation of water due to combustion. The term

$$\frac{\%H_2O \text{ (in fuel, wt.)} \times 21.41}{1 - \%H_2O \times 10^6 \text{ Btu/lb fuel, dry}}$$

converts the weight percent moisture content to a value of standard cubic feet per million Btu for the proper units in the equation. (Note: For the sake of simplicity, not all units are shown in the preceding equation.) The value of F_w will be known in all cases where high moisture contents are encountered, and the term (F_w - F_d) is then taken to be zero.

Another situation frequently encountered is the combination firing of fuels. This requires knowledge of the firing rates of each fuel or the percentage of total heat input accountable to each fuel. The total gas volume is then the sum of each individual F-factor calculation at the same excess air/temperature conditions. The following example will utilize both equations previously shown.

EXAMPLE -- Heat input rate = 100 x 10^6 Btu/h

50% of heat input attributed to coal

50% of heat input attributed to wood bark at 50% moisture and 9,000 Btu/lb (dry basis)

Stack temperature = 350°F

Stack oxygen content = 10.5 percent

Gas volume due to coal combustion would be calculated as follows:

F_d = 9,820 dscf/10^6 Btu

F_w = 10,680 wscf/10^6 Btu

Heat input = 50 x 10^6 Btu/h = 0.833 x 10^6 Btu/min

$$Q = 0.833\ [(9820 \times \frac{20.9}{20.9 - 10.5}) + (10{,}680 - 9{,}820)] \times \frac{350 + 460}{528}$$

$$= 0.833\ (19{,}734 + 860) \times 1.53$$

= 26,250 acfm at 350°F.

Gas volume due to wood bark combustion would be calculated as follows:

F_d = 9,640 dscf/10^6 Btu

$\%H_2O$ = 50% or 0.50

Heat input = 0.833 x 10^6 Btu/min

$$Q = 0.833\ [(9640 \times \frac{20.9}{20.9 - 10.5}) + \frac{.5 \times 21.41}{(1 - .5)(.009)}] \times \frac{350 + 460}{528}$$

$$= 0.833\ (19{,}375 + 2{,}380) \times 1.53$$

$$= 0.833\ (21{,}755)\ 1.53$$

= 27,725 acfm at 350°F

Total gas volume = 26,250 + 27,725 = 53,975 acfm at 350°F, 10.5% O_2.

Another related F-factor method utilizing the F_w value may be used for quick calculations of the gas volume. The equation is

$$Q = \text{heat input rate} \times [F_w + \text{stack oxygen correction factor}] \times \begin{matrix}\text{temperature}\\ \text{correction}\end{matrix} \quad (3)$$

Although technically less accurate than Equations 1 or 2, it will provide an estimated gas volume with little error at a moisture content of 10 percent or less. This equation will provide a different value from that derived by Equation 1 because of the method of measuring stack oxygen. The methods used in the field during an inspection (either O_2 Fyrite or Orsat) provide their measurements on a dry gas basis, whereas Equation 3 is intended to be used with the oxygen measurement on a wet gas basis. The effect of using the dry basis measurement is that the equation will produce results that are biased high. As the moisture content in the gas stream increases, the error becomes more significant.

SECTION 3

POLLUTION CONTROL EQUIPMENT

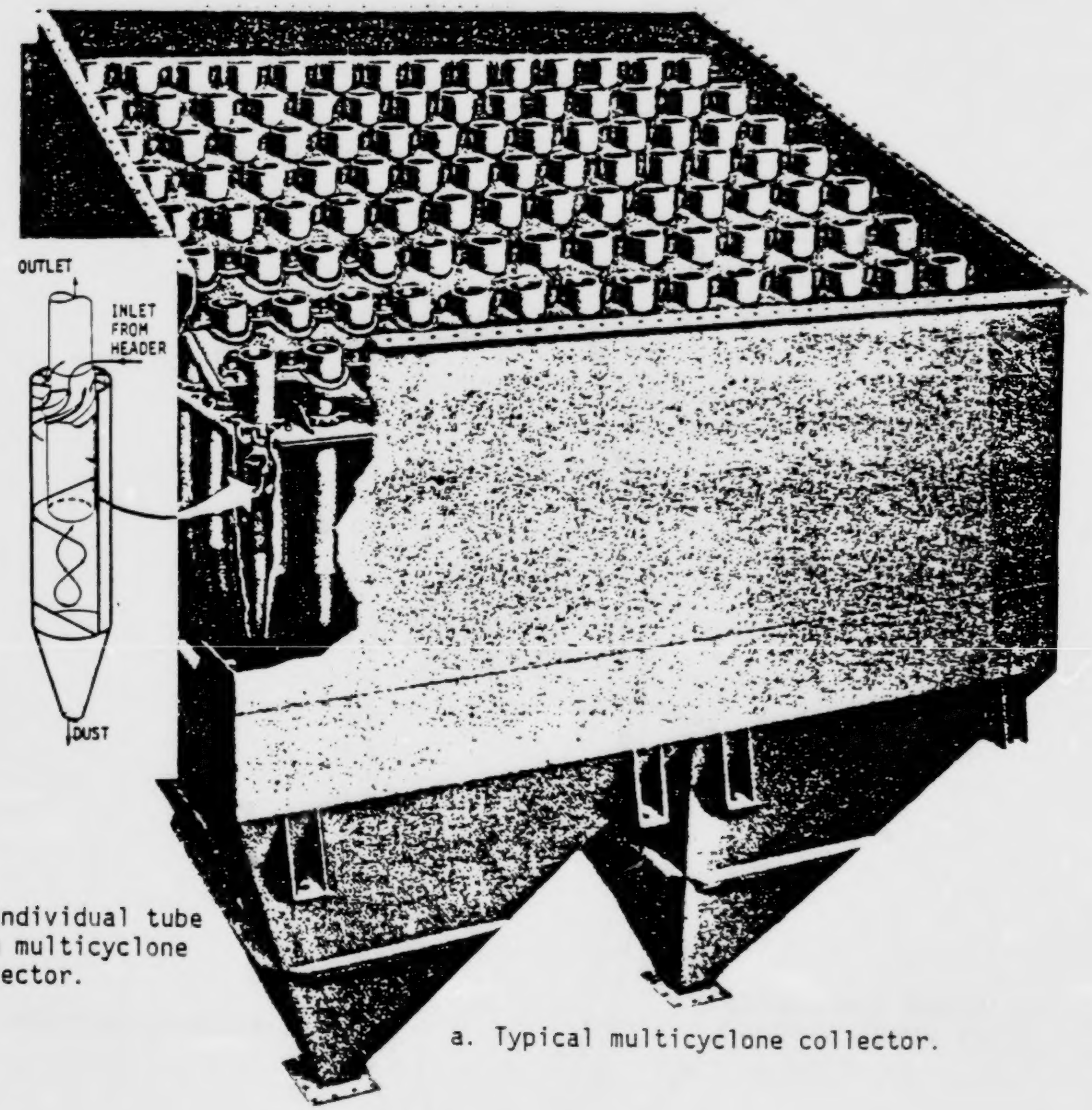
The selection of pollution-control equipment for industrial boilers to meet particulate emission standards depends on fuel type, method of combustion, fuel and ash characteristics, and the costs of available equipment to meet prescribed emission requirements. The available particulate-control devices include multicyclones, fabric filters, electrostatic precipitators (ESP's), and scrubbers. Each of these devices is discussed separately in the following subsections.

3.1 MULTICYCLONES

3.1.1 Introduction

The principal mechanical collector used on older industrial boilers is the multicyclone (Figure 18), which consists of several dozen to several hundred tubes. Only a few inches in diameter, each tube is a small cyclone collector. As shown in Figure 19, each of these tubes consists of a collection tube, a gas outlet tube, and a turning vane. When the unit is operating properly, gas flows helically down through the annular area between the outer cylinder and the gas outlet tube, and concentrations of particles move down the collection tube wall into the hopper. At the collection tube outlet, the vertical component of air flow reverses, and the cleaned gas passes upward out of the tube through the gas outlet tube.

Because the multicyclone is not very efficient in the collection of particles smaller than 10 μm in diameter, it cannot be used to control particulate matter from pulverized-coal-fired boilers. Since stoker-fired boilers emit larger particles, multicyclones can be used to control particulate emissions if emission regulations are not too restrictive. Figure 20 presents typical fractional efficiency curves for a multicyclone collector. Combustion problems can produce significant quantities of particulate matter as smoke, but smoke particles are so small that they will pass through a multicyclone.


OUTLET
INLET FROM HEADER
DUST

b. Individual tube from multicyclone collector.

a. Typical multicyclone collector.

Figure 18. Multicyclone collector.

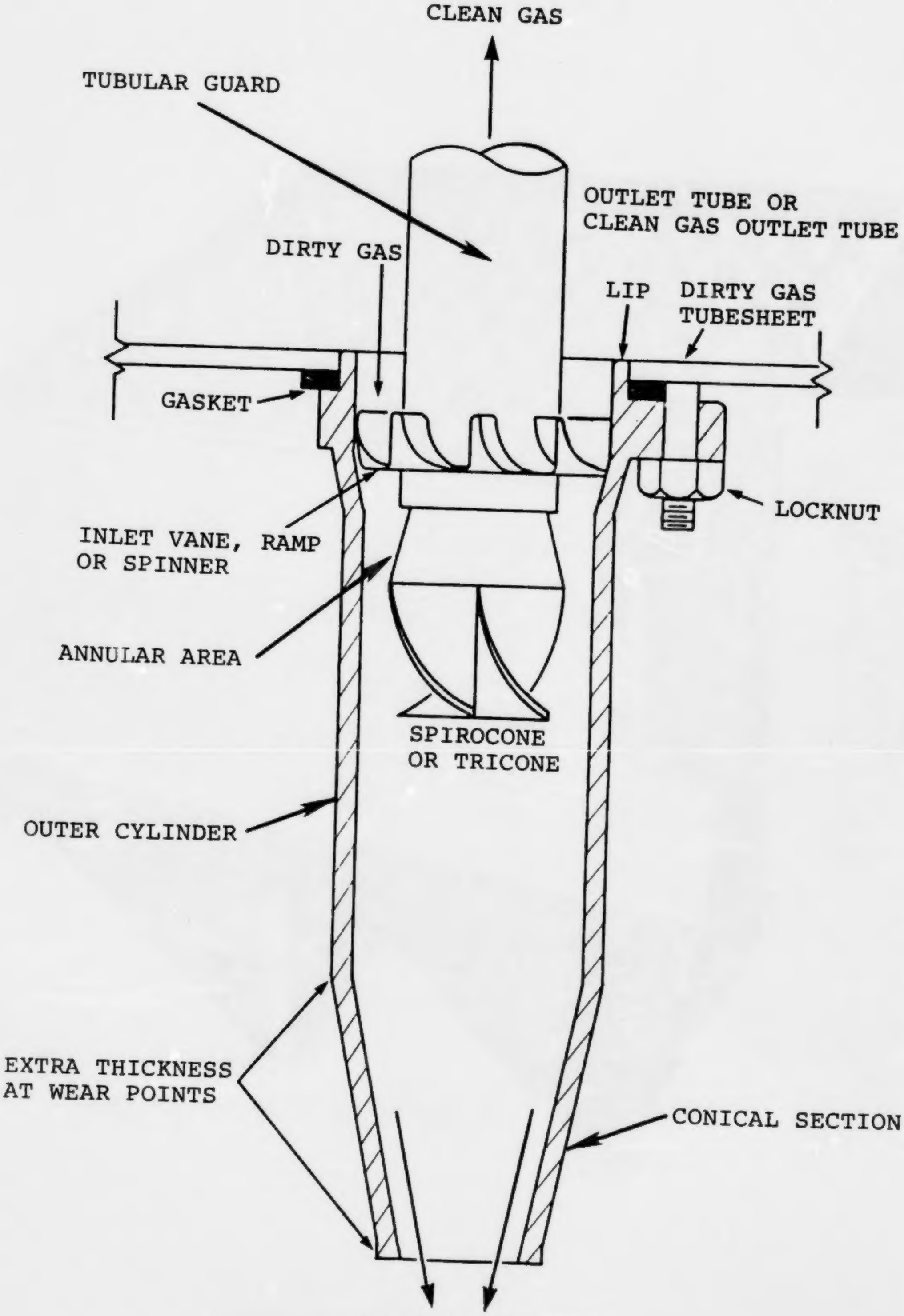

CLEAN GAS
TUBULAR GUARD
OUTLET TUBE OR
CLEAN GAS OUTLET TUBE
DIRTY GAS
LIP
DIRTY GAS
TUBESHEET
GASKET
LOCKNUT
INLET VANE, RAMP
OR SPINNER
ANNULAR AREA
SPIROCONE
OR TRICONE
OUTER CYLINDER
EXTRA THICKNESS
AT WEAR POINTS
CONICAL SECTION
FLY ASH PARTICLES

Figure 19. Cross section of an individual cast iron collection tube.

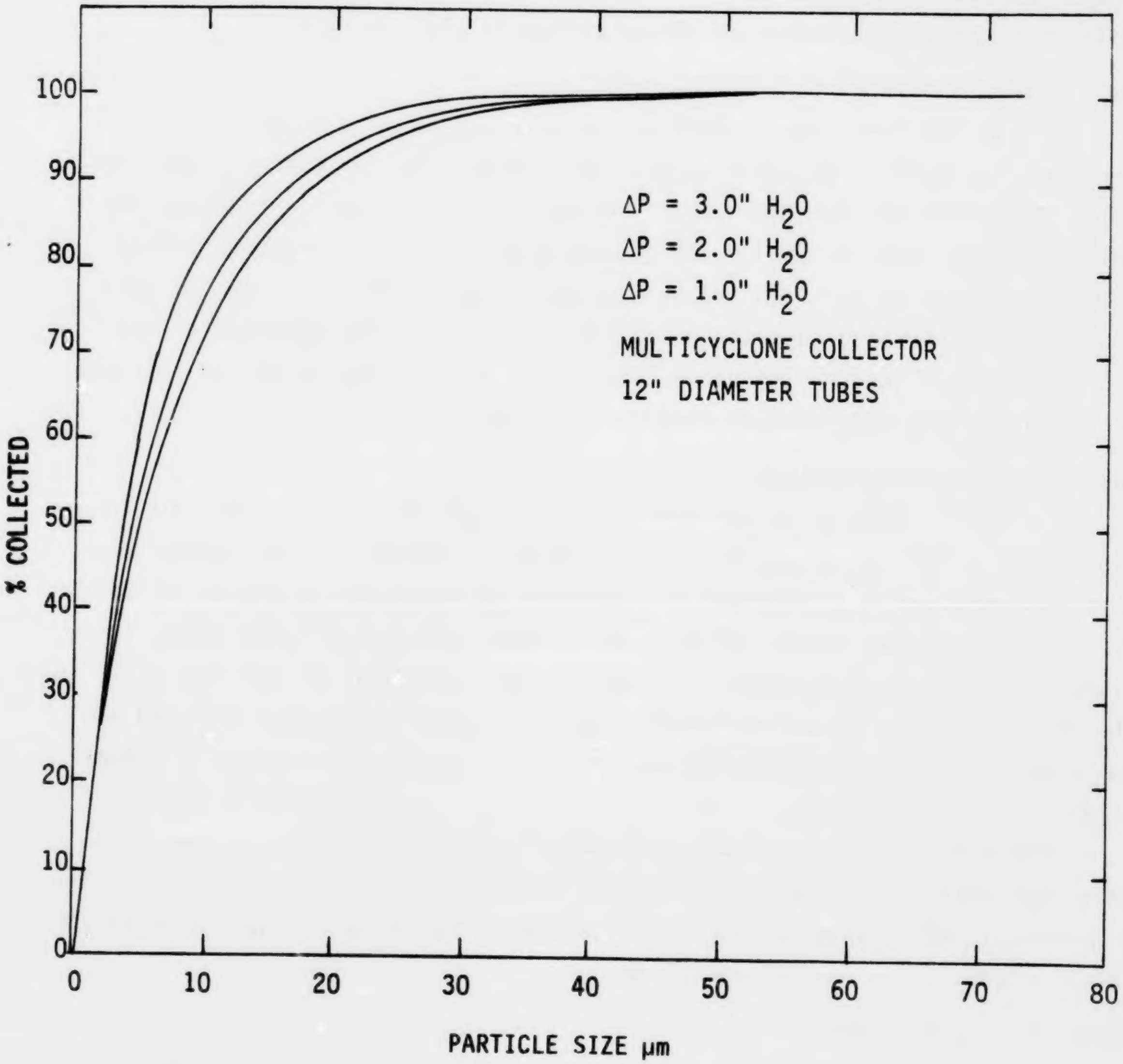


Figure 20. Fractional efficiency curves for multicyclone.

3.1.2 Operation and Maintenance

There are several operating conditions and/or malfunctions that can reduce cyclone performance. Most of these conditions result in disturbance of the cyclone vortex, pluggage of gas passages, or interference with the dust discharge from the cyclone tube. The following subsections identify the major failure mechanisms and their effect on collector efficiency.

Gas and Particulate Maldistribution --

For each cyclone tube to receive the same amount of dust or grain loading, the distribution of gas flow must be uniform both horizontally and vertically across the multicyclone inlet. Proper duct inlet design requires the use of turning vanes in many cases. Sharp duct turns or improperly joined ducts may result in particle stratification at the outer radius of the turn which causes increased abrasion and/or dust buildup on the approach to the collector tube inlet turning vanes. Figure 21 shows deposits at the entrance to the inlet of a multicyclone section as a result of particle fallout.

Gas Volume and Pressure Drop--

If the collector is to operate at maximum efficiency, the gas volume and pressure drop must be at maximum design values. Operation above design pressure drop may result in increased turbulence and decreased collector efficiency. Conditions that result in high gas volumes and high pressure drops include operation at high excess air, ambient air inleakage in the duct prior to the collector, and boiler overload. High excess air and boiler overload are not generally observed in utility boiler operations but are common in industrial boiler applications.

When the boiler is operated at reduced load (firing rate), it generates less-than-design flue gas volume and the collection efficiency decreases. The reduction in efficiency can be significant when the boiler is operating at 20 to 25 percent below design gas volume.

Inlet Turning Vane Wear--

The inlet turning vane or ramp is designed to impart a tangential motion to the inlet gas stream of the collector. This tangential motion is transformed into the vortex in the collecton tube. Impaction of particulate on the turning vane surface results in abrasion and metal wear over the life of the

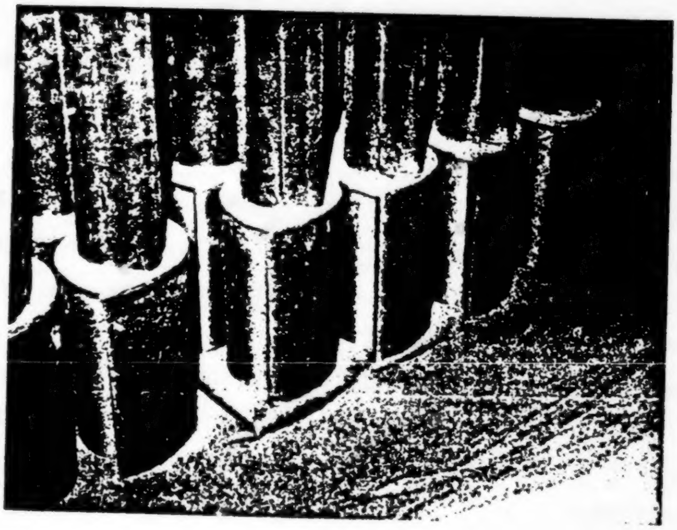


Figure 21. Particulate fallout on dirty gas tube sheet.

collection tube. Severe damage results in disturbance of the vortex and increased gas turbulence that limits collection efficiency. Figure 22 shows abrasive wear of inlet turning vanes.

Inlet Turning Vane Material Buildup--

Material buildup on the turning vane or ramp may occur as a result of particle fallout or it may develop as a scale. The scale occurs as sulfuric acid condenses on the cool metal surfaces at low boiler load conditions. Fly ash combines with the acid and forms a hard scale when the boiler load and flue gas temperatures increase.

The effect of inlet material buildup on collection efficiency is similar to turning vane wear in that the turning vane vortex is disturbed or it fails to form. An improperly developed vortex results in turbulence and short circuiting of the gas volume to the gas outlet tube without particle separation.

Collection Tube Wear--

Contact of abrasive particulate with the walls of the collection tube results in erosion of the tube and eventual failure of the collector tube. Normal wear occurs at the bottom of the cast iron tube. As the metal thins, holes may appear along the bottom of the tube or the dust outlet may become ellipical or egg shaped. These conditions result in a poorly formed gas vortex and an increase in surface roughness and turbulence. Erosion of the dust outlet opening increases particle reentrainment and decreases cyclone collection efficiency.

Collection Tube Scale--

Scaling in the collection tube as a result of acid dew point condensation results in increased surface roughness and particle reentrainment in the outlet gas vortex. Scaling may be periodically scoured by the fly ash in the vortex or it may develop into complete blockage depending on boiler operating temperatures, load swing, and concentration of SO_3 in the flue gas stream. Figure 23 shows scale development on the inside of a collection tube.

Gas Outlet Tube Blockage--

Scaling of the collector may also occur in the gas outlet tube. Because the cross sectional area of the outlet tube is less than the collection tube,

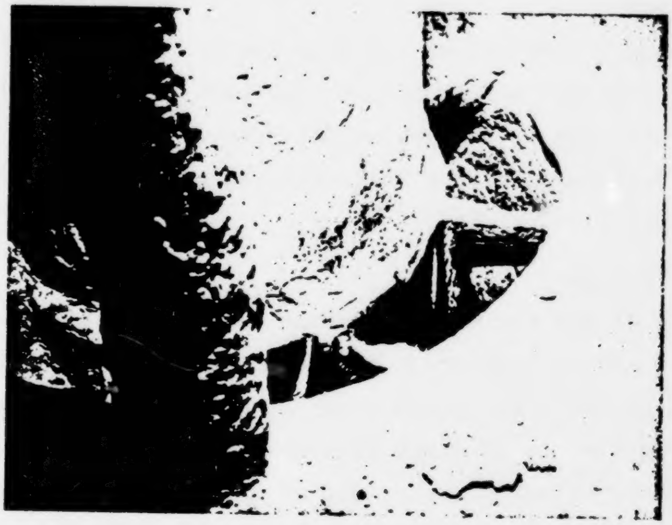


Figure 22. Inlet turning vane wear because of abrasion.

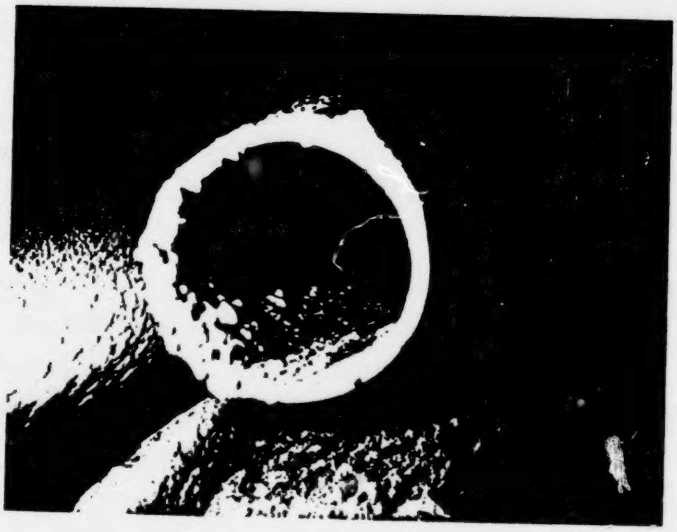


Figure 23. Scale on inside of collection tube.

a thick scale may close the tube completely. The removal of larger abrasive particles in the collection tube limits the self-cleaning scouring effect in the outlet gas stream.

Partial blockage of the outlet gas tube and increased static pressure drop reduce the gas volume passing through the tube and the separation efficiency. Complete blockage of the gas outlet removes the tube from service in a similar manner to blockage of the inlet turning vane. Figure 24 illustrates a plugged outlet tube.

Dust Outlet Tube Blockage--

Severe scaling of the cyclone collection tube may result in complete closure of the dust outlet opening at the bottom of the tube. Once plugged particulate begins to build up in the tubes, the turning vanes are restricted and there is no flow through the tube because of increased pressure drop. As with inlet turning vane blockage, the loss of the collection tube reduces the effective size of the collector and increases the gas volume through the remaining tubes. Figure 25 shows a plugged dust outlet tube.

Air Inleakage Into Ash Hopper--

In most industrial boiler applications, the flue gas handling fan is located down stream of the multicyclone (ID fan). This location places the collector and duct work under negative atmospheric pressure. Any opening in the flue gas stream results in significant air inleakage into the system.

Inleakage into the hopper area creates a gas flow from the hopper through the dust outlet of the collector tubes and into the gas outlet tubes. This flow, depending on the condition of the hopper seals, may account for 10 to 20 percent of the collector gas volume. The upward flow of gas through the narrow dust discharge opening at the bottom of the collection tube increases reentrainment of fine particulate at the dust outlet and reduces collector efficiency. Major points of hopper inleakage are: gaskets between shell flanges, poor welds, gasket between ash hopper and ash valve, ash valve, manhole door gaskets, door frame gasket, and inspection port.

Collection Bypass--

Bypass of small volumes of flue gas through the dirty gas and clean gas tube sheet allows a significant weight of particulate to be emitted. Major areas of bypass are the gasket seal between the collection tube and the dirty

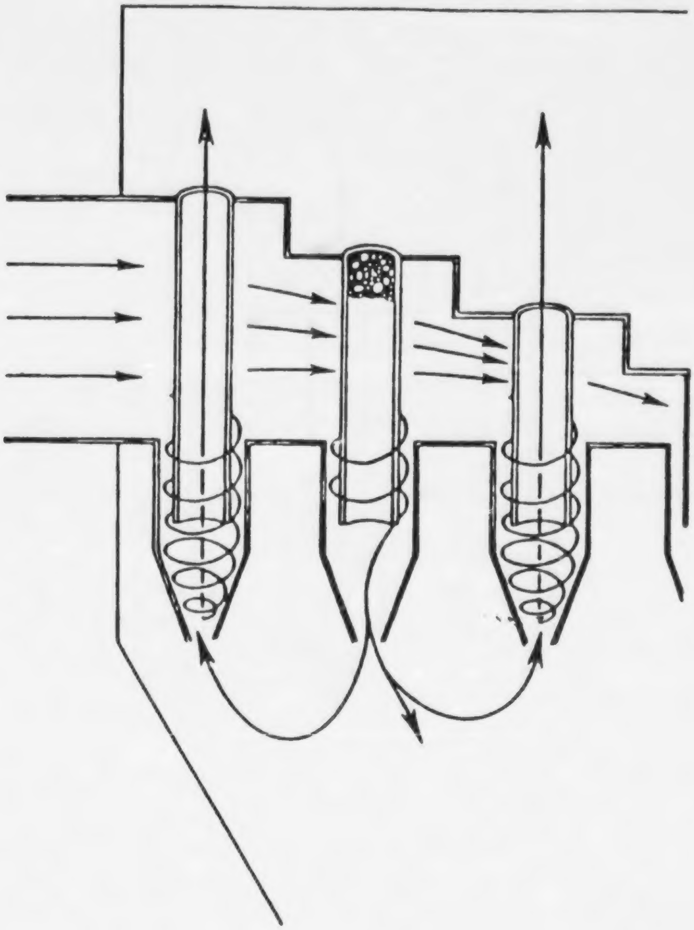


Figure 24. Plugged outlet tube.

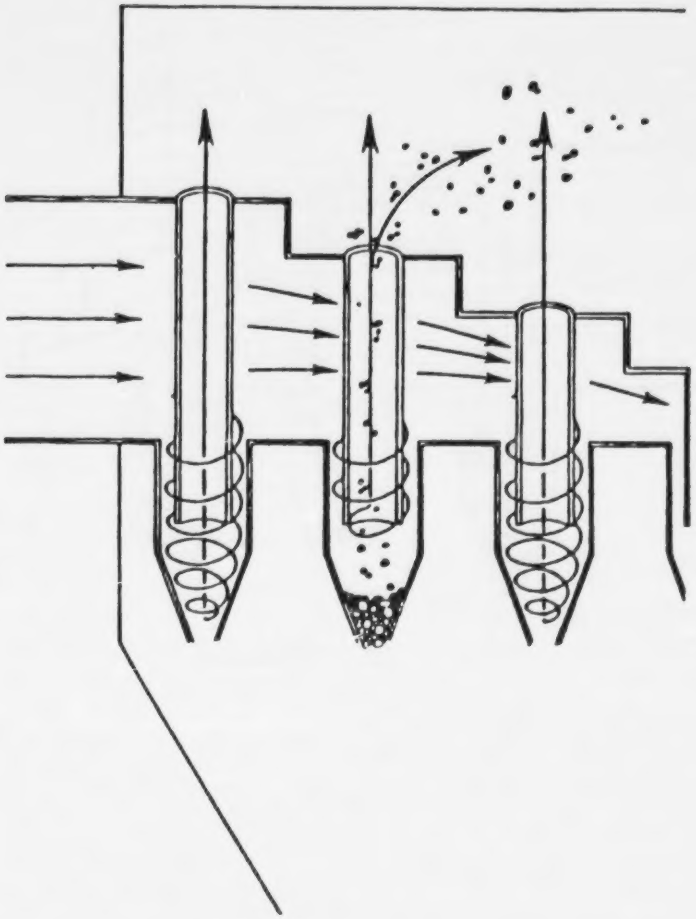


Figure 25. Plugged conical section.

gas tube sheet (Figure 26); welded or pressed joints between clean gas outlet tubes and the clean gas tube sheet (Figure 27); welded or bolted joints between tube sheets and collector shell (Figure 28); and welded or bolted joints between tube sheet sections (Figure 28).

Penetration may also occur through holes on the leading edge of the gas outlet tube in the dirty gas plenum. The tubes are exposed to the dirty gas and abrasive damage occurs as the gas is directed to the collection tube turning vanes. In most cases the pressure drop across the penetration point is equivalent to the collector pressure drop (3 to 4 inches H_2O) and allows substantial gas bypass through the orifice.

Because most bypass occurs internally to the collector, it is difficult to determine the points of inleakage while the collector is on-line. A visual inspection of the tube sheet, outlet tubes, gaskets, and welds can identify major penetration points and allow for correction. Many penetration points, however, are hidden and will be observed only under a static pressure differential. To find these leaks the collector must be sealed, pressurized and penetration observed visually with a white aerosol smoke.

Hopper Cross Flow--

Because of space limitations, multicyclone collectors are designed with multiple rows of collection tubes in the direction of gas flow. To achieve maximum efficiency the design must ensure that all collection tubes receive an equal volume of flue gas. As gas passes through the initial leading row of tubes, the total gas volume is reduced and the gas velocity in the plenum is reduced. To maintain uniform velocity in many designs, the clean gas tube sheet is inclined. In theory, this should maintain uniform flow to each row of tubes, but in practice the pressure drop across each row of tubes is not uniform and more gas is directed to the first tube rows. Systems having several tube rows and large nonsegmented hoppers experience cross hopper ventilation. Flue gas flows out of the dust discharge opening of the inlet tube. It flows across the hopper and up through the dust discharge of the back collection tubes (Figure 29). Flow across the hopper interferes with dust discharge and causes fine particulate to be reentrained. Flow into the dust outlet also disturbs the gas vortex which also prevents collection tube dust discharge.

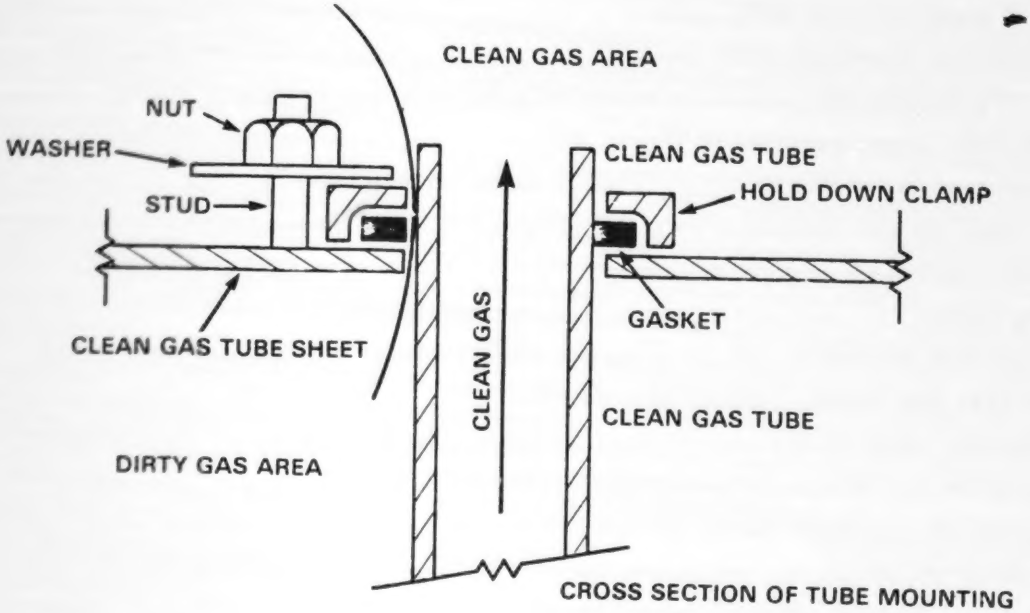

CLEAN GAS AREA
NUT
WASHER
STUD
CLEAN GAS TUBE
HOLD DOWN CLAMP
GASKET
CLEAN GAS TUBE SHEET
CLEAN GAS
CLEAN GAS TUBE
DIRTY GAS AREA
CROSS SECTION OF TUBE MOUNTING

Figure 26. Clean side air leaks.

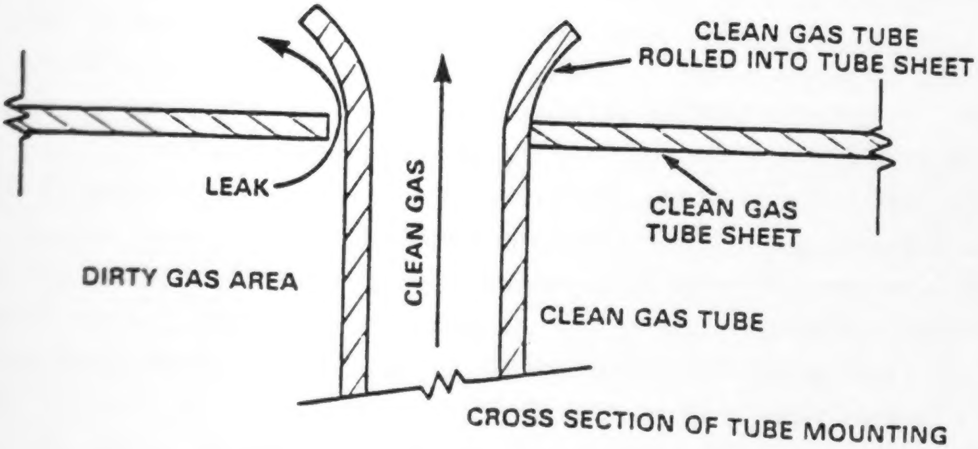

CLEAN GAS TUBE ROLLED INTO TUBE SHEET
LEAK
CLEAN GAS
CLEAN GAS TUBE SHEET
DIRTY GAS AREA
CLEAN GAS TUBE
CROSS SECTION OF TUBE MOUNTING

Figure 27. Example of leaks in clean gas outlet tubes and clean gas tube sheet.

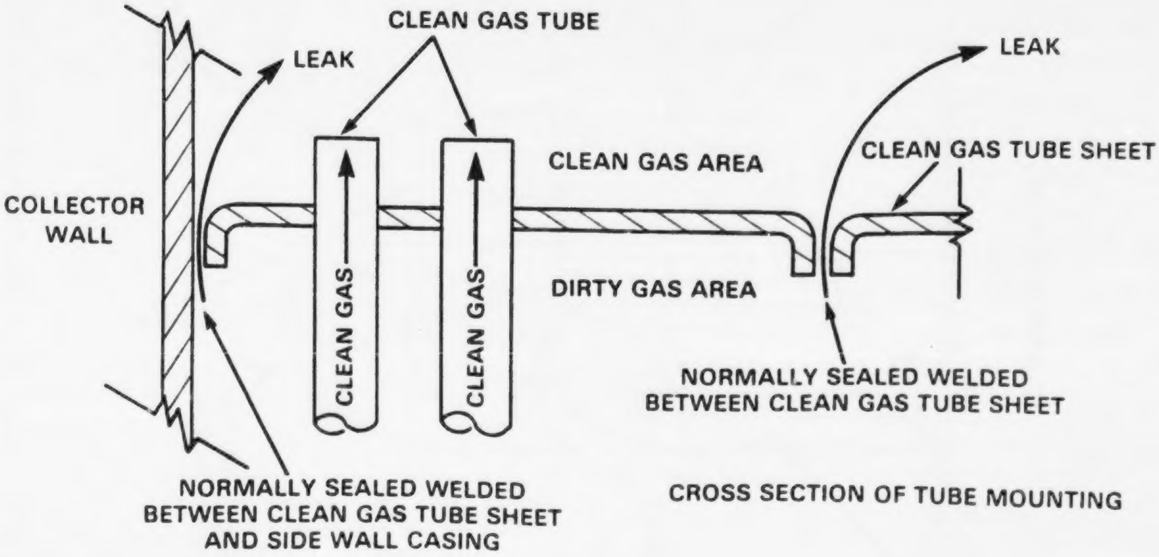

CLEAN GAS TUBE
LEAK
LEAK
CLEAN GAS AREA
CLEAN GAS TUBE SHEET
COLLECTOR WALL
CLEAN GAS
CLEAN GAS
DIRTY GAS AREA
NORMALLY SEALED WELDED BETWEEN CLEAN GAS TUBE SHEET
NORMALLY SEALED WELDED BETWEEN CLEAN GAS TUBE SHEET AND SIDE WALL CASING
CROSS SECTION OF TUBE MOUNTING

Figure 28. Clean side air leaks.

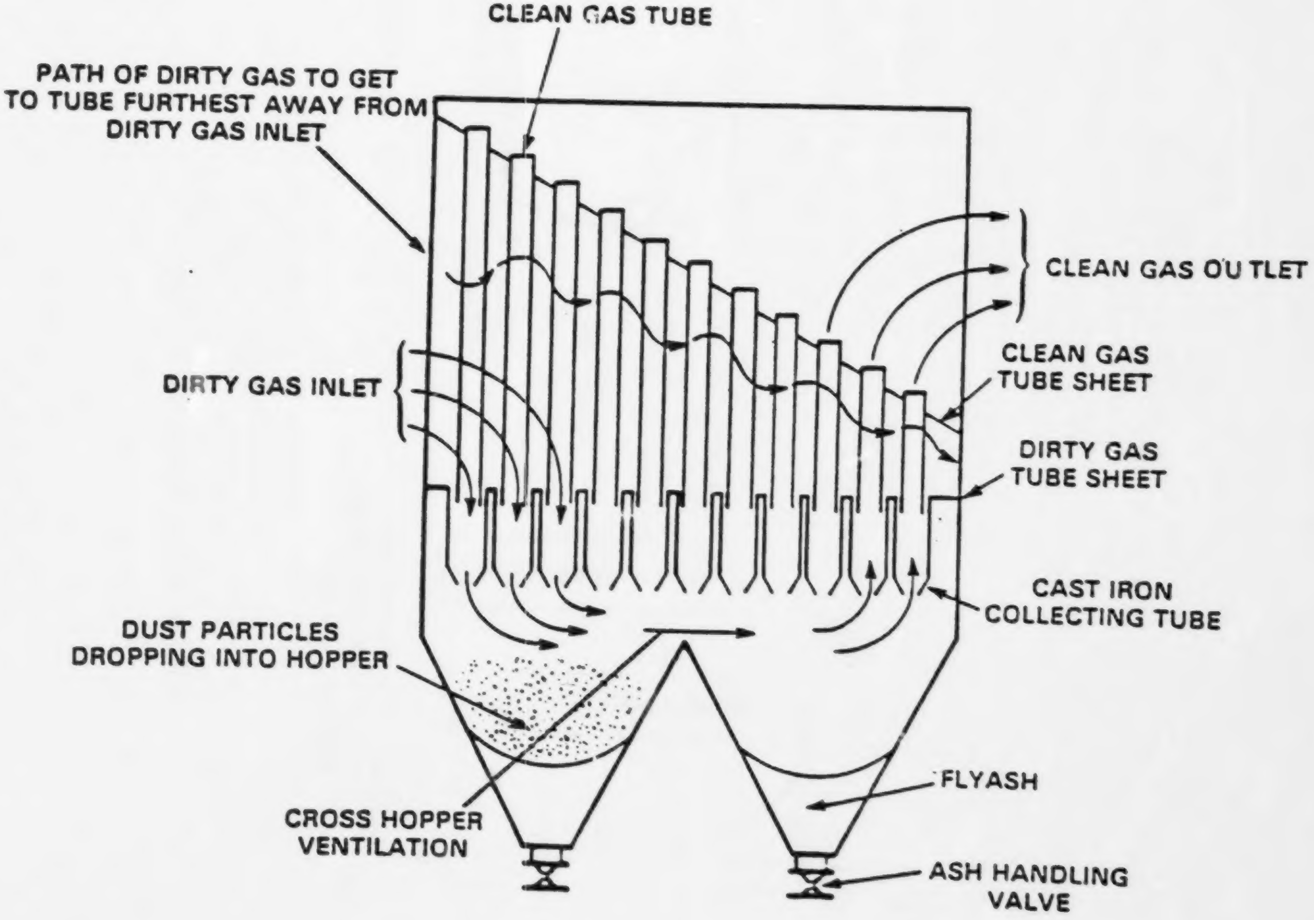

CLEAN GAS TUBE
PATH OF DIRTY GAS TO GET TO TUBE FURTHEST AWAY FROM DIRTY GAS INLET
CLEAN GAS OUTLET
DIRTY GAS INLET
CLEAN GAS TUBE SHEET
DIRTY GAS TUBE SHEET
CAST IRON COLLECTING TUBE
DUST PARTICLES DROPPING INTO HOPPER
FLYASH
CROSS HOPPER VENTILATION
ASH HANDLING VALVE

Figure 29. Poor distribution and cross hopper flow.

Cross hopper ventilation can be prevented by using a welded baffle at the hopper valley. Segmenting the hopper provides a more uniform pressure drop distribution across the tube sheet. Cross flow is aggravated when the tubes are plugged, when scale has formed on outlet tubes, or when there is hopper infiltration.

3.1.3 Inspection Procedures

The inspector should perform the following at the start of the boiler multicyclone inspection:

1. Determine opacity.
2. Measure system pressure drop.
3. Measure air volume.
4. Measure system temperature.
5. Measure fan speed.
6. Measure fan static pressure.
7. Measure inlet particle size distribution (if possible).
8. Measure hopper discharge weight (if possible).
9. Measure wet bulb and dry bulb temperatures.

After these external inspections are completed, the following internal inspections should be performed at a future time when the unit can be taken off line and cooled sufficiently. Note: Be sure and follow proper safety procedures described on Pages 130 to 133 for confined entry.

1. Check for inlet distribution buildup.
2. Check for inlet vane plugging.
3. Check for outlet tube plugging.
4. Check for hopper bridging.
5. Check for inleakage (corrosion, moisture, or scale).
6. Check for leakage between clean and dirty air sides.

Using the manufacturers' design parameter specifications (tube diameter, number of tubes, etc.) the inspector should calculate the inlet velocity at maximum and minimum process flow conditions. These calculated values indicate the multicyclone efficiencies at maximum and minimum boiler conditions. The inspector may find that recirculation or flow control is required at low boiler loads for compliance with emission standards.

During system field evaluations, the inspector should note observations at both low and high boiler loads. The external inspection allows the inspector to obtain sufficient data to estimate air volume (using fan speeds, static pressure, and temperature) and to determine whether a potential operating problem exists (e.g., moisture content or weight discharge from hopper). These data, when used with stack test data, allow future comparisons of system operating conditions and performance. The internal inspection reveals operating design problems that may not be determined by external inspections. Such problems (e.g., uneven distribution, inlet plugging, inleakage, and leakage from the clean-to-dirty side) are not always indicated by changes in system static pressure but can significantly reduce overall efficiency. From the external and internal inspection data and from efficiency data supplied by the manufacturer, the inspector can determine the multicyclone mass emission rate and can anticipate long-term maintenance and operational problems.

3.2 FABRIC FILTERS

3.2.1 Introduction

Fabric filters are becoming increasingly popular for the control of particulate matter from pulverized-coal-fired boilers, and they are used occasionally on stoker-fired boilers. The particulate collection efficiency of fabric filters is higher than for any other device. Other principal advantages are that they minimize emissions and circumvent the resistivity problems associated with some coals. The capital costs of fabric filters generally are less than those of ESP's, but they are more than those of mechanical collectors or scrubbers. The operating costs for fabric filters are usually somewhat higher than those for ESP's and mechanical collectors, but lower than those for scrubbers.

A problem in the application of fabric filters to stoker-fired boilers is control of coal properties and the combustion process. A spreader-stoker operation is sensitive to the size of the coal, particularly the quantity of fines in the coal. Excessive fines cause carbon carryover that sometimes blinds the fabric with sticky particulate matter. Blinding results in excessively high pressure drops, a reduction in the air flow through the boiler, and a reduction in boiler capacity.

The fabric filter is usually designed for high-temperature operation, and either fiberglass or polytetrafluoroethylene bags are used. Reverse-air and pulse-jet bag cleaning mechanisms may be used. Reverse air units (on industrial plants) are generally limited to an air-to-cloth ratio (A/C) of 2.5 acfm/ft^2 of cloth area. Pulse-jet units can operate at an A/C of 4.0 to 4.5 acfm/ft^2. A precleaner such as a multicyclone or a simple impaction baffle plate is usually employed to remove the larger, more-abrasive particles before they enter the fabric filter. The normal operating pressure drop across a fabric filter is between 3 and 6 inches H_2O. Higher pressure drops have been experienced on industrial systems. A typical fabric filter is shown in Figure 30.

3.2.2 Operation and Maintenance

Theoretically, fabric filters can achieve mass collection effiencies in excess of 99.5 percent when particles are as small as 0.1 μm. In practice, many process conditions and installation problems can reduce both the collection efficiency and the time available for service. Fabric filters require extensive preventive maintenance and inspection to reduce periods of excess emissions. The subsequent subsections discuss operation and maintenance of fabric filters. Because reverse air units are more commonly used, the emphasis is on this type.

Factors Affecting Bag Life--

Dust is removed from the gas stream by passing the gas through a porous fabric upon which the dust deposits and builds a dust cake layer. The efficiency of dust collection depends on the integrity of the fabric structure supporting the dust cake. Any deterioration of the fabric structure that allows localized failure increases the penetration of dust through the system.

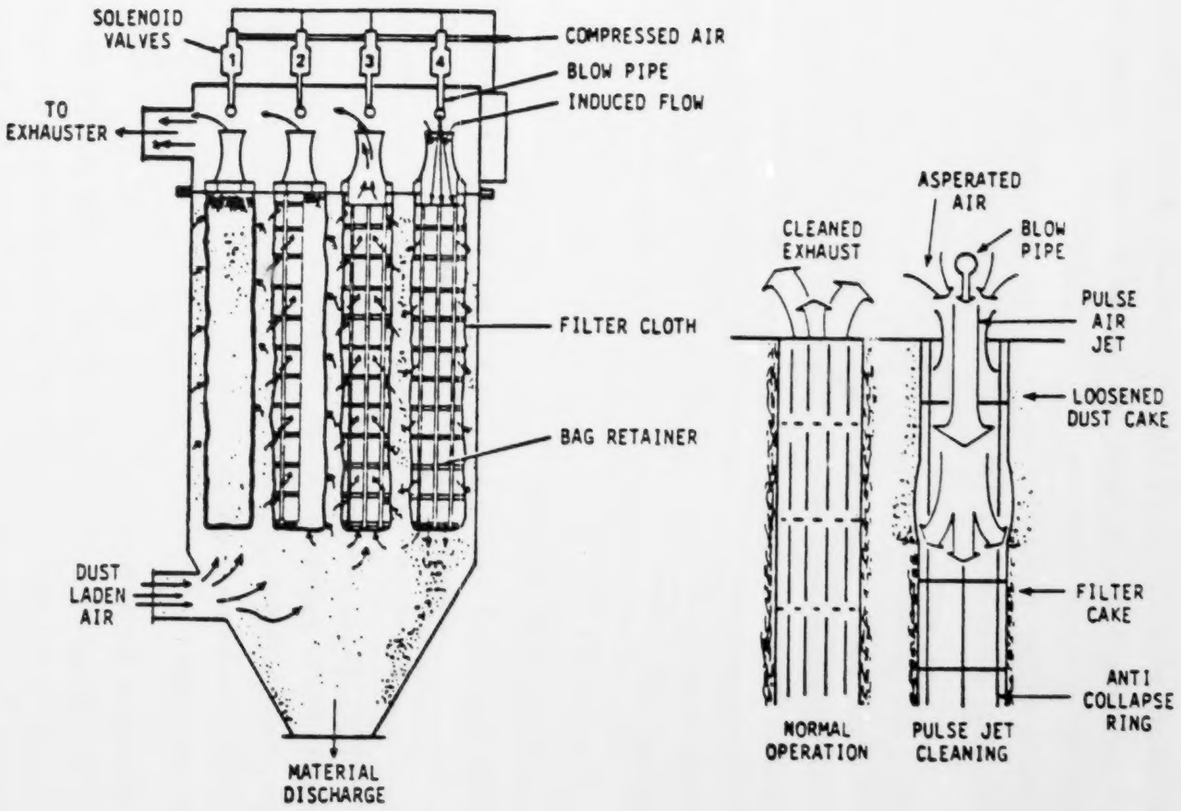

SOLENOID VALVES
1
2
3
4
COMPRESSED AIR
BLOW PIPE
INDUCED FLOW
TO EXHAUSTER
FILTER CLOTH
BAG RETAINER
DUST LADEN AIR
MATERIAL DISCHARGE
CLEANED EXHAUST
ASPERATED AIR
BLOW PIPE
PULSE AIR JET
LOOSENED DUST CAKE
FILTER CAKE
ANTI COLLAPSE RING
NORMAL OPERATION
PULSE JET CLEANING

Figure 30. Typical reverse-pulse baghouse during cleaning.

Temperature Excursion--

The most common cause of bag failure from polymer chain breakage is exposure to high temperatures. Exposure to temperatures at or near the recommended continuous operating temperature level results in random chain breakage with reduced tensile strength over the life of the fabric. Typical life of fiberglass bags at 325°F is between 12 and 24 months in service on a industrial boiler. The life may be greatly reduced if the fabric filter is simultaneously exposed to acids and moisture.

Exposure to temperatures above the recommended continuous operating temperatures for a few minutes may not result in immediate failure, but will reduce the overall life of the fabric. The effects of repeated temperature excursions on tensile strength are cumulative. A high-temperature alarm with an automatic method for bag protection (e.g., quenching, dilution, or bypass) should be provided.

Pressure Drop--

In normal operation, the system pressure drop remains between the upper limit set for cleaning (time duration between cleaning periods or pressure) and the lower level after cleaning. An increase in static pressure drop between cleaning (upper limit) indicates a change in fabric/cake resistance (permeability). This change can result from changes in amount of cake buildup retained, oil deposits from the compressed air system, or moisture from inleakage. The increased pressure drop may be tolerated if it is not severe or if it does not decrease ventilation performance because of decreased volume of gas exhausted.

If an increase in pressure drop occurs, attempts should be made to diagnose the cause (oil, moisture), and corrective action should be taken. An increase in cleaning energy beyond manufacturers' recommendations should not be made, because it shortens bag life.

Cake Release--

The ability to remove collected particulates (cake) from the fabric surface determines the cleaning frequency required for the filter system. Factors that affect the energy necessary to remove the cake include cake composition, porosity, and the effectiveness of the energy transfer to the cake/filter interface.

The presence of moisture either from operation below the dewpoint or from inleakage through the shell presents a similar problem. The cake release is impaired, and increased energy is required to remove the cake. When the boiler is shut down, it is advisable to continue to operate the baghouse for one complete cycle (including cleaning). This operation purges it with clean air to avoid condensation and ensure that bag contaminants are removed.

Cleaning Intensity--

The removal of the dust cake requires the breaking of the cake structure. Too little energy does not break the cake, and too much energy increases bag failure because of fiber abrasion. The proper intensity is defined as the minimum amount necessary to remove the proper amount of cake. Each boiler is unique, and identical boilers at a site may not have the same cake release properties because of source variability and/or gas stream characteristics. Therefore, the required cleaning intensity must be matched to the system.

The proper cleaning of the bag requires the flexing of the surface to dislodge the cake. If bag tension is low, the bag may be flexed adequately at the top, but the standing wave dampens as it is transmitted downward. The installation of each bag must be checked to ensure proper tension. Manufacturers' literature should be consulted to determine the correct tension method. The fabric may elongate because of the weight of dust collected between cleaning cycles or bag tongues may slip in hangers. Thus, tension may change with time of service.

In reverse-air collectors, the cake is released by collapsing the bag with reversal of gas flow. The bag is flexed, and the cake removed from the surface by the cleaning gas. In systems with short bags [i.e., bags less than 2.5 m (8 ft) long], bags may be allowed to collapse almost completely. The bag must be reinflated in a snap action, and a dwell time must be allowed for the dislodged cake to flow from the bag before gas filtration commences. In this case low bag tension results in complete closure of the bag near the thimble, reduction of reverse gas flow through the bag, and consequently reduction of cleaning efficiency (Figure 31).

Tube Sheet Bridging--

In shaker or reverse-air fabric filters, dust cake is collected on the interior surface of the bags. The removal of the collected dust cake requires

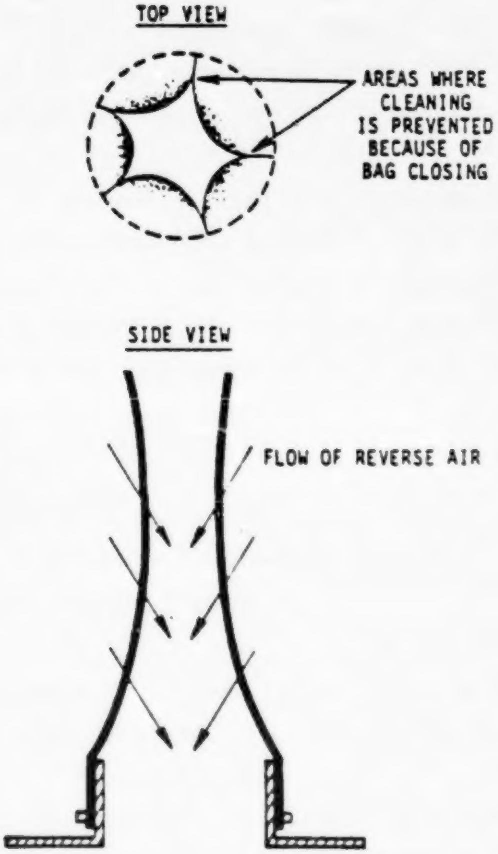

TOP VIEW
AREAS WHERE CLEANING IS PREVENTED BECAUSE OF BAG CLOSING
SIDE VIEW
FLOW OF REVERSE AIR

Figure 31. Impaired cleaning in a reverse-air fabric filter.

the free fall of the dust through the thimble and into the dust hopper. When systems are uninsulated or when the gas temperature is near the dewpoint, cake accumulates on the underside of the tube sheet and on the inside of the thimbles. Heat is transferred from the tube sheet to the uninsulated baghouse shell. The colder metal reduces dust temperatures and causes agglomeration and deposition on the surface.

As caking increases, the ability of the dust to discharge through the thimble is reduced. Eventually, complete bridging of the bag results. In severe cases, the accumulation may extend several feet into the bag. The bridging occurs most commonly near the baghouse shell (outside rows) or near doors where air inleakage from deteriorated gaskets occurs (Figure 32). The bridge may normally be dislodged by flexing the bag with the hand near the top of the thimble. The dust above the bridge, because it is exposed to the gas stream, is free flowing and discharges after the cooler cake is broken near the tube sheet.

The breaking of the cake only returns the bag to service for a short period; bridging soon recurs. Continued operation in this condition decreases net cloth area and increases pressure drop. The higher A/C ratio increases bag abrasion and decreases bag life. The solution to the problem is to reduce heat loss through the tube sheet/shell by installing insulation or increasing the system temperature.

Abrasion--

The failure of the fabric may occur over a long period of time because of the abrasive action of dust particles on individual fibers in the structure. The failure may result from general abrasion over a large area or specific attacks in concentrated areas.

Local intensive abrasion, which results in premature bag failure, is undesirable and can be prevented. High abrasion rates are commonly associated with improper bag installation or design flaws in the collector. Some common causes of failures are described below. Each case of abrasion failure must be addressed separately to determine if corrective action may be taken to reduce the frequency of failures.

In shaker and reverse-air fabric filters, the bag can be attached to the tube sheet by a thimble and clamp ring design or by a snap ring design. Figure 33 shows the two methods of attachment. Dust enters the baghouse

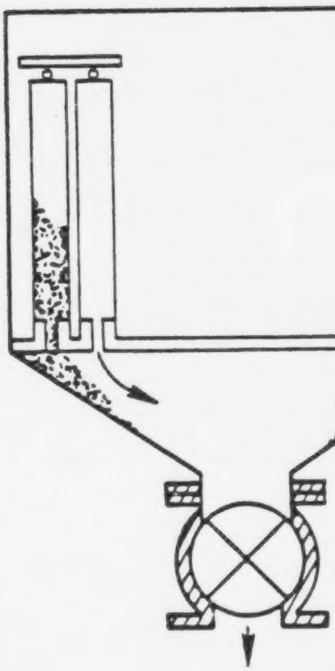


Figure 32. Bridging near baghouse shell caused by cooling a poorly insulated fabric filter.

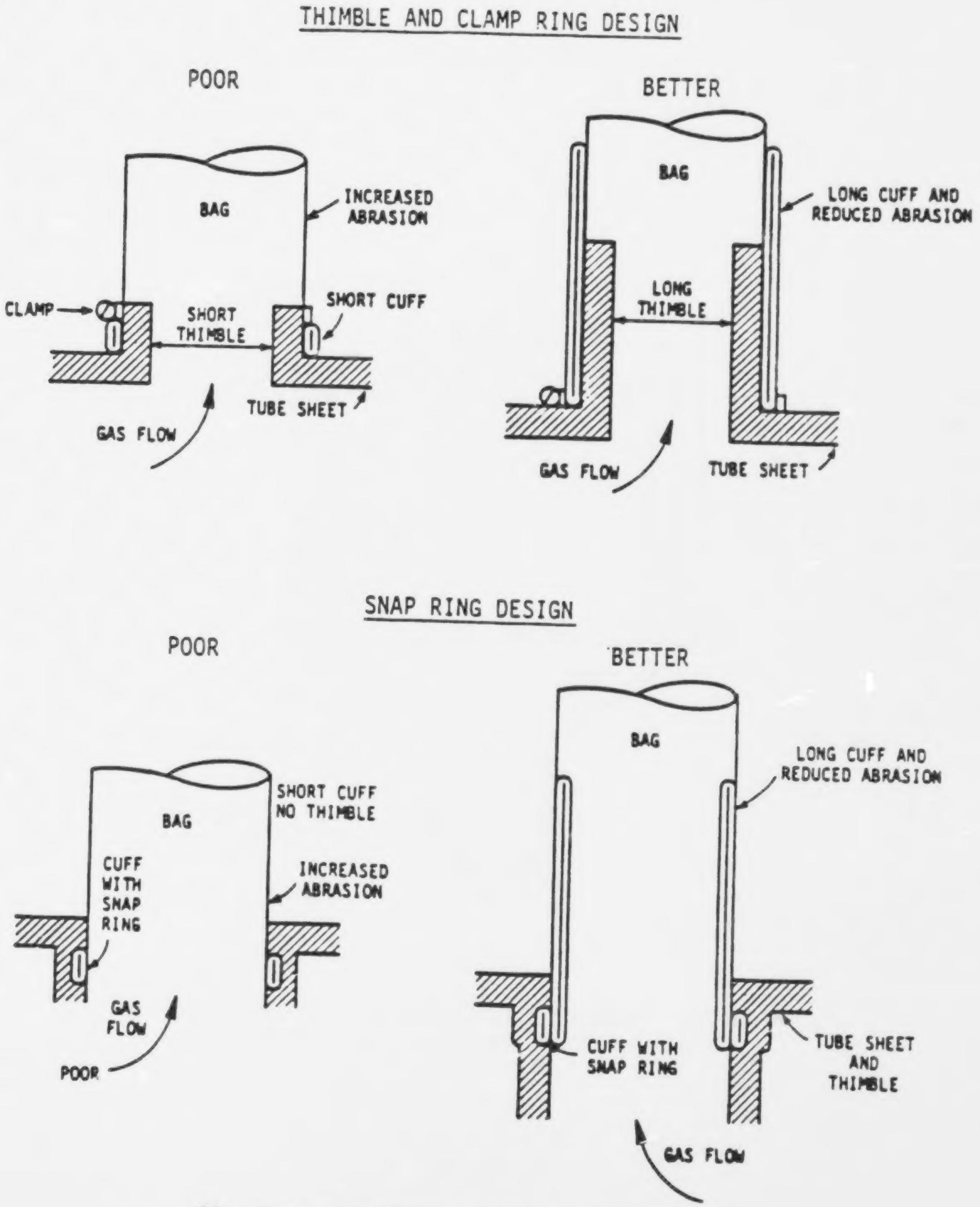

THIMBLE AND CLAMP RING DESIGN
POOR
BETTER
BAG
INCREASED ABRASION
CLAMP
SHORT THIMBLE
SHORT CUFF
TUBE SHEET
GAS FLOW
BAG
LONG CUFF AND REDUCED ABRASION
LONG THIMBLE
GAS FLOW
TUBE SHEET
SNAP RING DESIGN
POOR
BETTER
BAG
SHORT CUFF NO THIMBLE
CUFF WITH SNAP RING
INCREASED ABRASION
GAS FLOW
POOR
BAG
LONG CUFF AND REDUCED ABRASION
CUFF WITH SNAP RING
TUBE SHEET AND THIMBLE
GAS FLOW

Figure 33. Methods of bag attachment in shaker and reverse-air fabric filters.

filter at the hopper in a horizontal direction and must turn vertically to enter the tube sheet thimbles. Heavy particles with higher inertia do not follow the flow and therefore do not enter the opening parallel to the thimble walls. The particles impact on the walls of the thimble and, if the thimble is short, on the fabric above the thimble. The action of the particles striking at an angle to the fiber surface increases abrasion. Roughly 90 percent of bag failures occur near the thimble. The use of double-layered fabric (cuffs) or longer thimbles reduces the failure rate.

In the snap ring system no thimble is used, and in some cases a cuff is not used. This exposes the bag to rapid abrasion a few inches above the snap ring. Add-on tube sheet thimbles may be used to reduce the effect.

Baffle plates or diffusers may be used to deposit large particles in the hopper before they contact the bags. The orientation of the plates is critical, however, because deflection of incoming gas into the hopper can resuspend collected dust and increase effective dust loading through the tube sheet. The resuspension is reduced if the hoppers are operated with continuous dust removal; thus, dust remains below the gas inlet. A cyclone also may be installed as a precleaner to remove larger particles and reduce inlet loading.

It is common practice not to remove dust that accumulates on the clean side of the tube sheet. The presence of dust is not a significant problem as long as penetration is not occurring. Heavy dust accumulation, however, results in rapid abrasive failure of serviceable bags. When the dust that has been emitted from previous bag failures settles on the tube sheet and collects around a bag, the weight collapses the bag and forms an orifice (Figure 34). The reduction in area increases gas velocity and therefore abrasive damage to the bag in the area of the restriction. The increased tension of the bag also results in abrasion of the bag where it contacts the top edge of the thimble. Prompt removal of accumulated dust from the tube sheet after a bag failure can reduce damage to other bags.

Chemical Attack--

The fabric types used in fabric filters in industrial boilers are Nomex Teflon®, and coated fiberglass. Nomex is particularly susceptible to sulfuric acid attack below the acid dewpoint. Fiberglass is susceptible to attack by hydrogen fluoride (HF) although this normally is not a problem in industrial

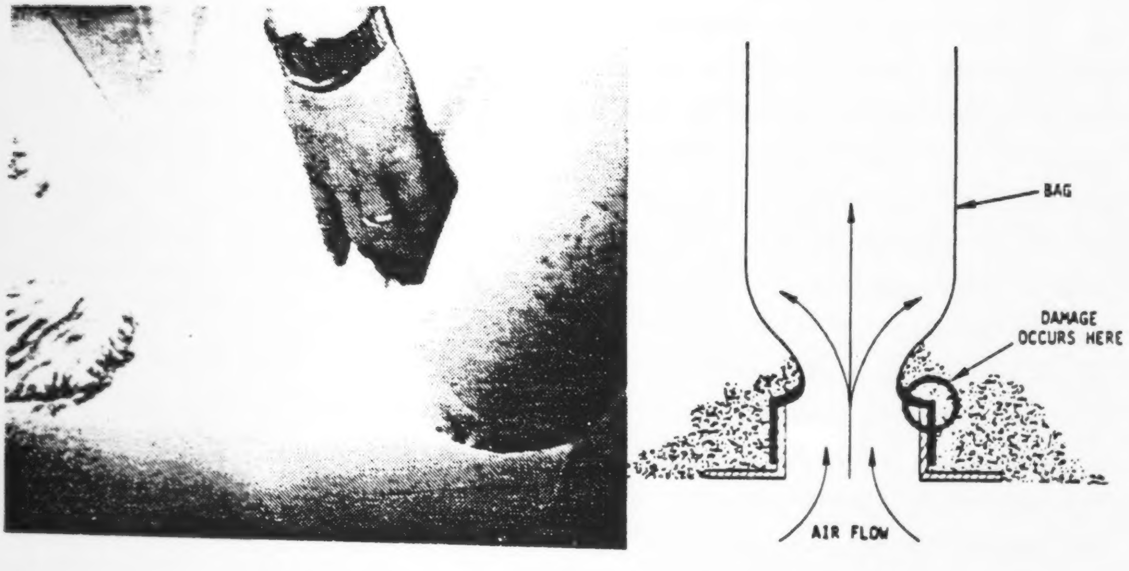

BAG
DAMAGE OCCURS HERE
AIR FLOW

Figure 34. Abrasive damage caused by accumulation of dust on the tube sheet.

boilers. The fabric filter should be operated at the lowest temperature consistent with avoiding moisture or acid condensation.

When boilers frequently shut down, bags can quickly be destroyed because of temperature excursions through the acid and moisture dewpoints. Shutdown should be accomplished by exhausting flue gases from the filter with dilution air (ambient) before cooling gases below the dewpoint. The purging removes the SO_2 and water vapor before condensation can occur on bag surfaces.

Installation of Bags--

The improper installation of bags can result in premature failure of the bags and increased emissions. The capital cost due to these failures can become significant and reduce production if downtime is required to change bags. This subsection is included to supplement manufacturers' instructions for installation of bags. The items covered are those that have been demonstrated by field experience to result in high bag failure rates.

Bags in shaker and reverse-air systems should be installed from the outer walls toward the center of the compartment. Bags should be hung according to manufacturers' recommendations by loop/hanger, eye-bolt/J-hook, or tongue/hanger assemblies. Each bag should also be inspected before hanging to ensure that it has no holes, is the proper size, and has a proper seam. Normally, the bags should be hung by row, the cuffs should be placed over thimbles, and the ring clamps should be attached. The fit of the bag over the thimble should be checked, and loose fitting bags should be discarded. Small bags that fail to meet specifications should not be forced over the thimbles.

After a bag is clamped, the tension should be adjusted to the manufacturer's specifications by using a spring tensioning device or tightening the bag to a known length. In no case should the bag be allowed to hang freely and fold over the thimble. Also, tension must be uniform in all bags to provide uniform cleaning efficiency.

When a bag farther than the second row from the walkway must be replaced, the intervening bags should be temporarily removed to allow safe installation of the replacement bag. Otherwise, the intervening bags can be stretched and damaged, the proper installation and tensioning of the replacement bag can be difficult. Figure 35 illustrates correct and incorrect installation of bags. To avoid snagging and puncturing bags, maintenance personnel should not carry tools while in the compartment.

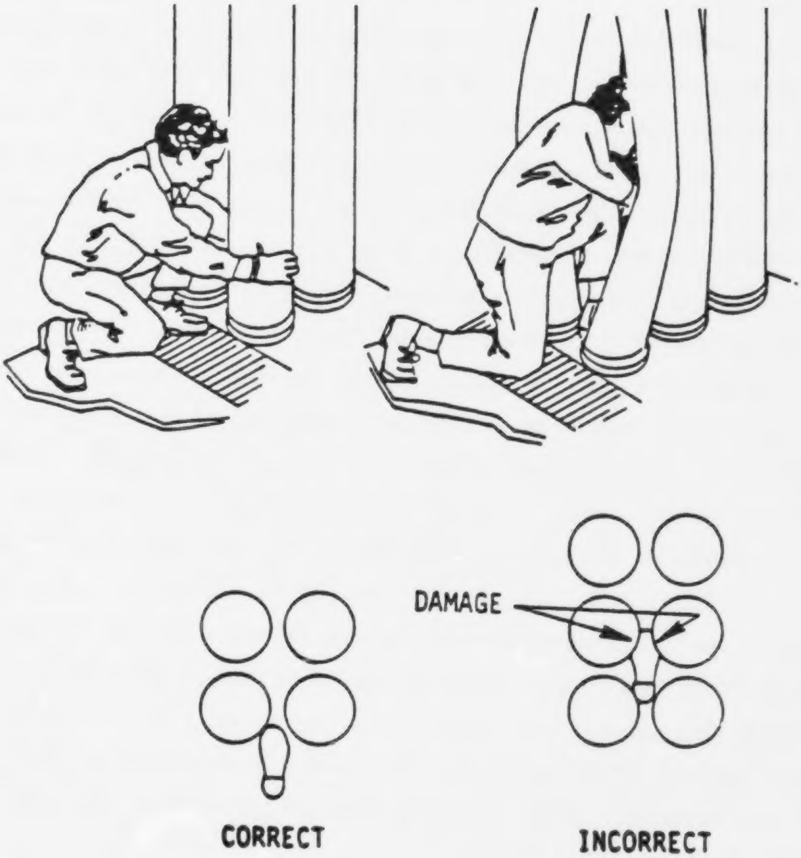

DAMAGE
CORRECT
INCORRECT

Figure 35. Correct and incorrect installation of bags.

The proper installation of a snap-ring-type bag requires collapse of the ring inward with the fingers and insertion of the cuff into the tube sheet opening. The circular portion of the ring should be placed in the seat, and the ring should be released. Fingers should be placed inside the ring allowing the bag to collapse into the tube sheet opening, and the ring should be pressed into place. The bag should be tensioned as necessary (Figure 36).

Hopper Bridging--

Bridging is a term applied to the blocking of dust discharge through an opening by the agglomeration of the dust. Bridging commonly occurs a short distance above the apex of the fabric filter hoppers and results in partial or complete closure of the discharge.

Common causes of the agglomeration are moisture, oils, and temperature drop. In fabric filters that operate below or near the dewpoint, the added drop in temperature in the hopper as a result of radiative cooling initiates agglomeration of the dust. Moisture enhances agglomeration of the dust, and cake gradually builds up. The area available for dust discharge is reduced and complete bridging eventually occurs. Agglomeration can be initiated by a drop in dust temperature resulting from air inleakage through flanges, gaskets, doors, or weld failures in the hopper.

Continuous or repeated occurrences of hopper bridging indicate a chronic temperature or moisture control problem in the ventilation and control equipment system. Careful inspection of hoppers should be made to determine gas inleakage points, and repairs should be made. Bridging is not a common problem in tight systems that are insulated and that operate at proper temperatures.

Dampers--

Dampers are used to direct gas flows or isolate compartments for cleaning or repair. If these dampers do not function to seal the compartment in shaker fabric filters or to change the direction of gas flow in reverse-air fabric filters, proper cleaning of the bags cannot be accomplished. Malfunction increases pressure drop, but in multiple-compartment systems does not necessarily shut the system down. Because all dampers leak under adverse conditions, dampers and seats should be inspected to minimize leakage.

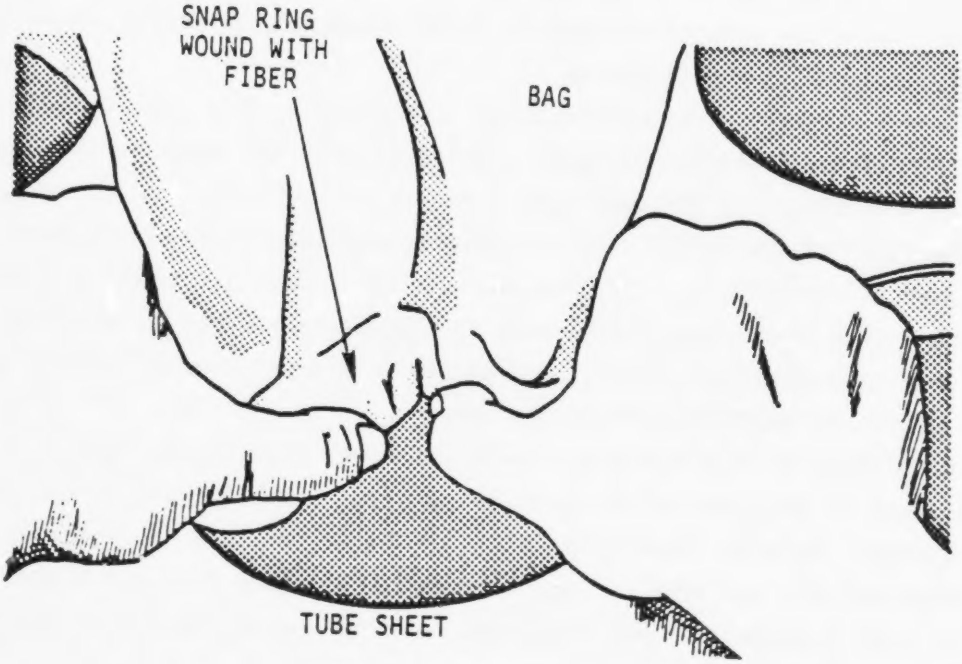

SNAP RING WOUND WITH FIBER
BAG
TUBE SHEET

Figure 36. Proper method of installing bag in tube sheet with snap rings.

Compressed Gas System--

The air used to activate the dampers and pulse-clean bags must be clean and dry. An in-line gas dryer (such as a dessicant, refrigerant, or filter) should be used to remove oil and water from the gas stream prior to introduction to the filter. As a safety precaution, a reserve tank with blowdown should be used at the filter to collect oil and water. If not collected, oil and water blind bags and can freeze in diaphragms during cold weather. The dryer should be serviced according to the manufacturer's recommendations. An internal inspection of the filter bags should be conducted periodically to check for oil and water.

Pulse Diaphragms--

Pulse diaphragms are used to open the valve seat in pulse-jet cleaning systems and provide a sharp finite surge of compressed gas through the blow tube to the venturi. The diaphragm in the closed position is held against the seat by compressed air and a spring. The compressed air is discharged through a solenoid valve and creates a pressure differential, which pulls the diaphragm from the seat. This momentarily allows passage of gas under the seat. Closure of the solenoid valve reestablishes the seal.

The solenoid commonly fails because of water freezing in the gas stream or because of electrical failure. In either case, the cleaning pulse cannot be initiated. If the solenoid does not seat, a constant release of compressed gas is heard.

The cleaning system can also fail because of diaphragm rupture or improper diaphragm seating. Constant bleeding of compressed gas into the blow tube is then heard.

A reduction in cleaning efficiency can occur if the diaphragm returns to the seat sluggishly. This can be caused by water, oil, or grit fouling the return spring, and can be detected audibly as a sharp pulse that trails off.

In evaluating the pulse cleaning system, the inspector should inspect the reserve air tank for water and listen for malfunctions of each pulse system through one cleaning cycle.

3.2.3 Inspection Procedures

Internal inspections of fabric filters are the only truly reliable means for identifying fabric filter problems. An external check only determines gross emissions (high opacities) caused by missing or torn bags. Items that should be checked in an external inspection include:

- Pulse jet system pressure
- Solenoids
- Reverse air blowers
- Shakers
- The solids removal system, including the screw conveyor, the pneumatic conveying system, heaters, and vibrators.

Pressure drop across each compartment and the total fabric system should be measured. However, pressure drop measurements are only effective for indicating if a compartment is out of service since pressure drop tends to equalize over the compartments, even those with missing or plugged bags. Comparison of the overall pressure drop with previous inspection measurements can indicate trends in overall fabric filter condition.

Internal inspections can indicate many of the problems and malfunctions discussed earlier. However, internal inspections must be made with the unit off-line; adequate safety precautions should be taken to insure that safety is not compromised. Safety precautions are outlined in Section 4.

The internal inspection checks the condition of the fabric bags. The inspector should look for bag tears, bag deterioration either by erosion or corrosion, missing bags, bags with oil from a compressed-air system, wet bags from acid dewpoint problems or inleakage, improper bag tension, and deposits on the clean air side of the fabric filter. Hoppers can be checked for incomplete solids removal and corrosion. Appendix A contains a detailed checklist for performing a fabric filter inspection.

3.3 ELECTROSTATIC PRECIPITATORS

3.3.1 Introduction

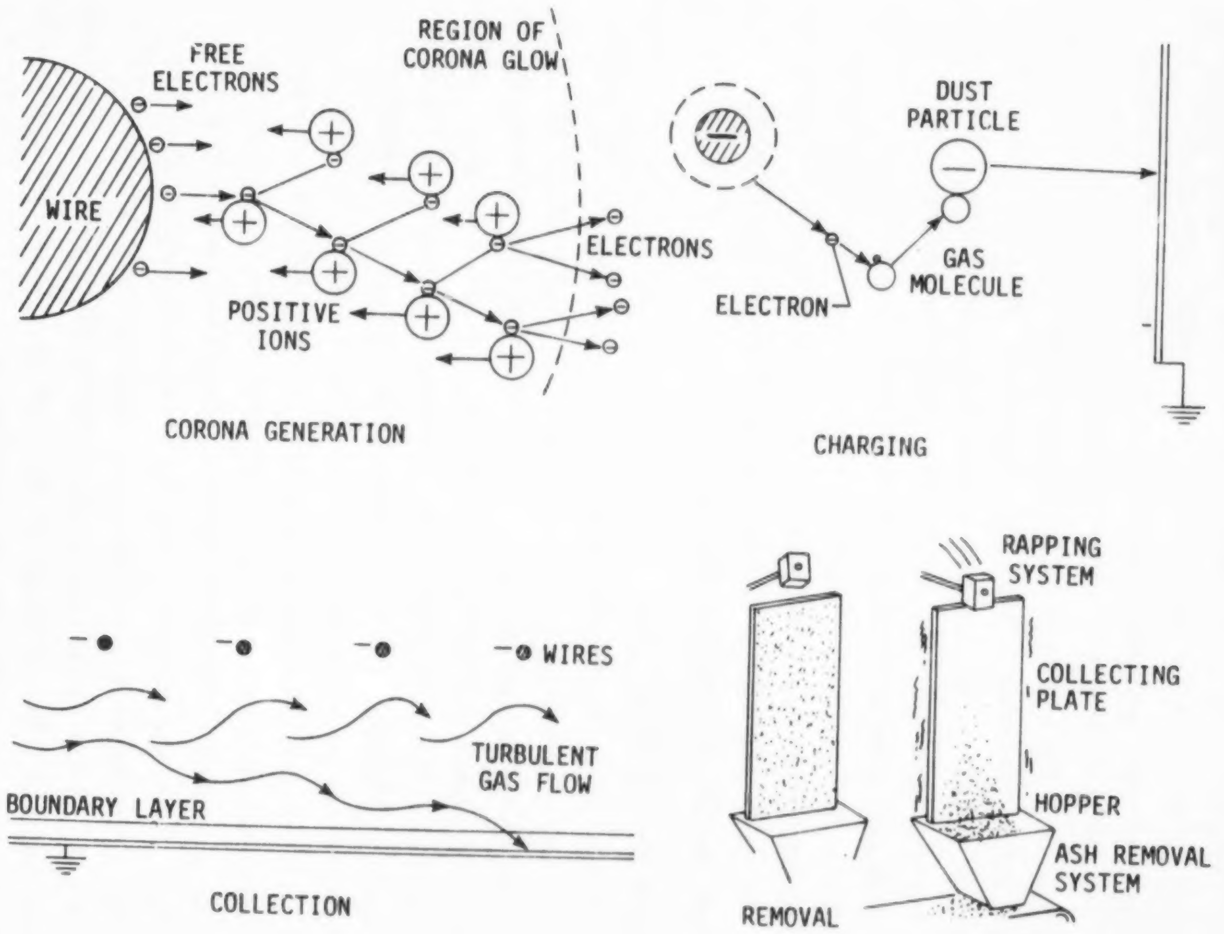
Electrostatic precipitators incorporate three basic processes: 1) transfer of electric charge to suspended particles in the gas stream, 2) establishment of an electric field to remove the particles to suitable collecting electrodes, and 3) removal of particles from the electrodes and particle collection with as little loss to the atmosphere as possible. Figure 37 illustrates these basic processes.

An ESP consists of a thermally insulated steel housing, its internal components, and its power supply equipment. The internal components include grounded steel plates (collecting electrodes) and metal rods or wires (discharge electrodes) that are suspended between the plates. The discharge electrodes are insulated from ground and are negatively charged at 15,000 to 80,000 volts d.c.[6] The electrical field between the wires and plates ionizes electronegative gas molecules (e.g., O_2, SO_2) that charge the suspended particles. The electrical charge creates a force on the particles (about 3000 times the force of gravity) that pulls them toward the collection plates. The collected dust particles are removed by periodical rapping of the collection plates, which causes the dust to fall in sheets into a receiving hopper.

Most precipitators use plate-type collection electrodes and pyramidal hoppers. Figure 38 presents an example of this type of precipitator. Gas flow through the ESP is normally horizontal.

3.3.2 Resistivity Effects

Dust resistivity outside the range of 10^8 to 10^{10} ohm-cm can greatly limit precipitator performance. Fly ash resistivity depends primarily on the chemical composition of the ash, the ambient flue gas temperature, and the amounts of water vapor and sulfur trioxide (SO_3) in the flue gas. At temperatures below 80°C (175°F), current conduction occurs principally along the surface layer of the dust and is related to the absorption of water vapor and other conditioning agents in the flue gas. Resistivity of fly ash is inversely related to the amount of SO_3 and moisture in the flue gas. Because low-sulfur coal releases very little SO_3, high-resistivity fly ash results. At elevated temperatures up to 200°C (400°F), conduction takes place primarily through the bulk of the material, and resistivity depends on the chemical composition of the material. Carbon carry-over has very low resistivity and is hard to hold on the collecting plates. Above 200°C (400°F), resistivity is generally below the critical value of 10^{10} ohm-cm. Figure 39 shows a typical relationship between resistivity and temperature.


FREE ELECTRONS
REGION OF CORONA GLOW
WIRE
ELECTRONS
POSITIVE IONS
DUST PARTICLE
GAS MOLECULE
ELECTRON
WIRES
TURBULENT GAS FLOW
BOUNDARY LAYER
RAPPING SYSTEM
COLLECTING PLATE
HOPPER
ASH REMOVAL SYSTEM

CORONA GENERATION

CHARGING

COLLECTION

REMOVAL

Figure 37. Basic processes involved in electrostatic precipitation.

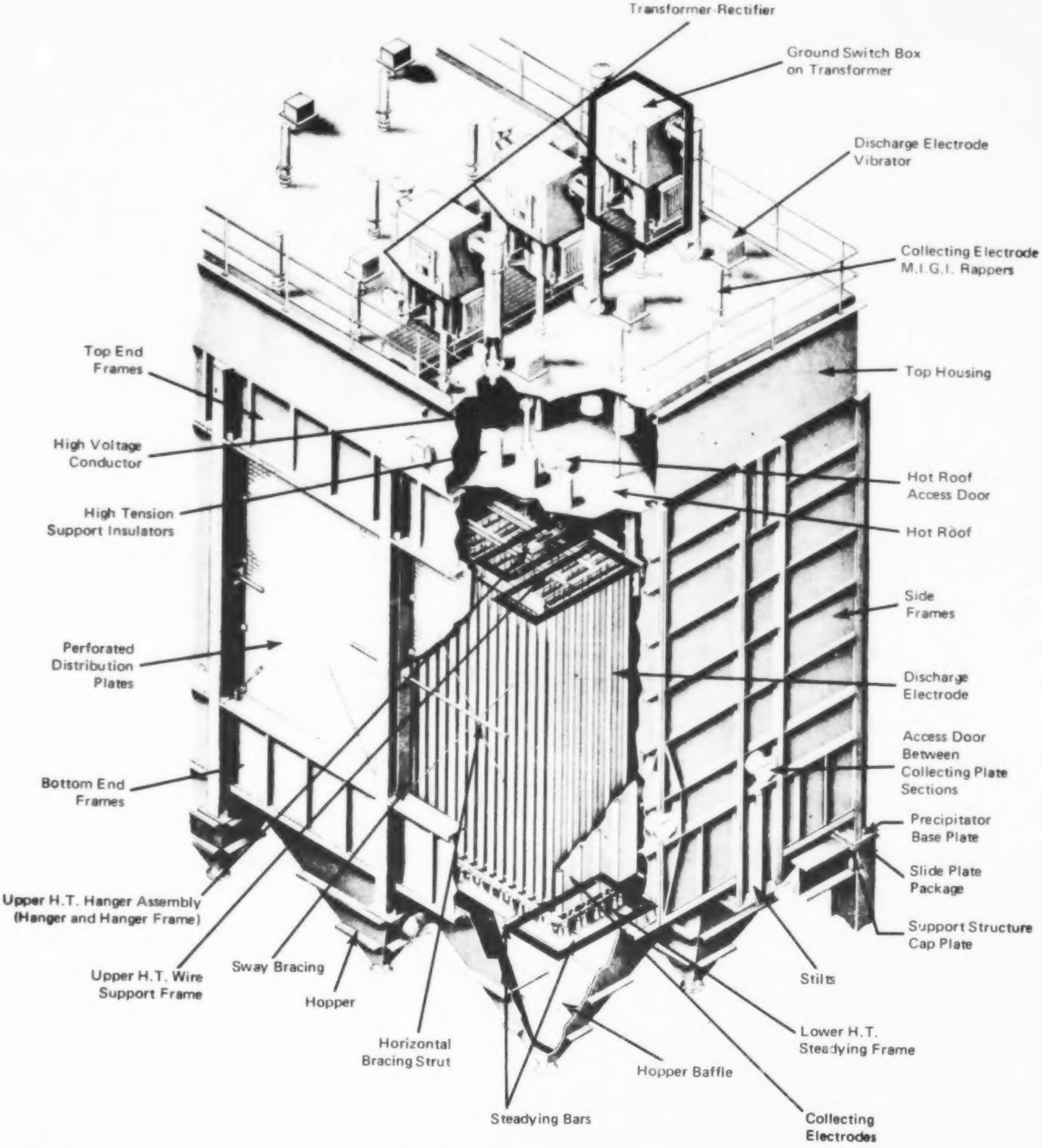

Transformer-Rectifier
Ground Switch Box on Transformer
Discharge Electrode Vibrator
Collecting Electrode M.I.G.I. Rappers
Top End Frames
Top Housing
High Voltage Conductor
Hot Roof Access Door
High Tension Support Insulators
Hot Roof
Side Frames
Perforated Distribution Plates
Discharge Electrode
Access Door Between Collecting Plate Sections
Bottom End Frames
Precipitator Base Plate
Slide Plate Package
Upper H.T. Hanger Assembly (Hanger and Hanger Frame)
Support Structure Cap Plate
Sway Bracing
Upper H.T. Wire Support Frame
Stilts
Hopper
Horizontal Bracing Strut
Lower H.T. Steadying Frame
Hopper Baffle
Steadying Bars
Collecting Electrodes

Figure 38. Typical electrostatic precipitator with top housing. Courtesy of Research Cottrell.

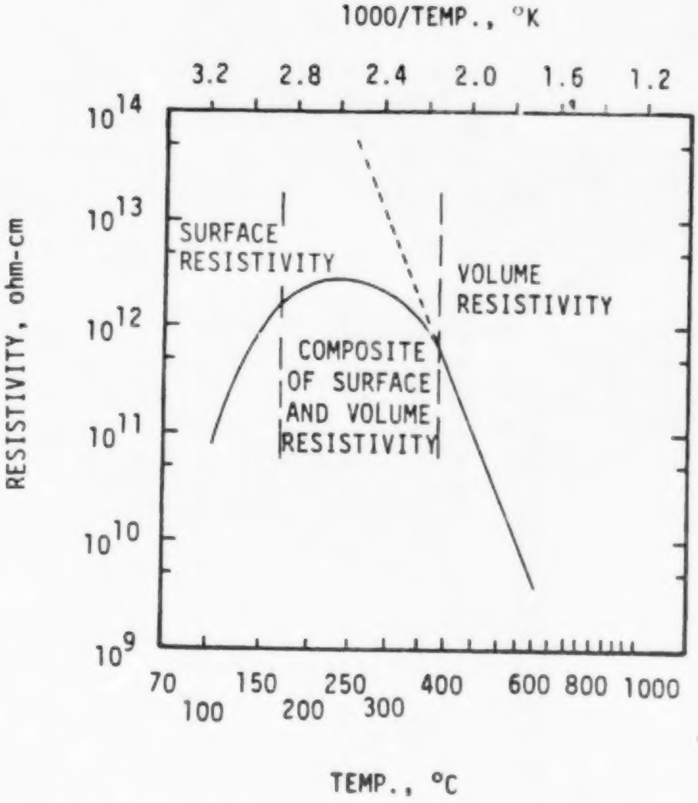


Figure 39. Typical temperature-resistivity relationship.

3.3.3 Instrumentation

Reliable ESP performance depends on the effective control of operating parameters. An ESP should be equipped with instrumentation to monitor and record the major operating parameters that indicate ESP performance, and the inspector should be able to understand these basic ESP data.

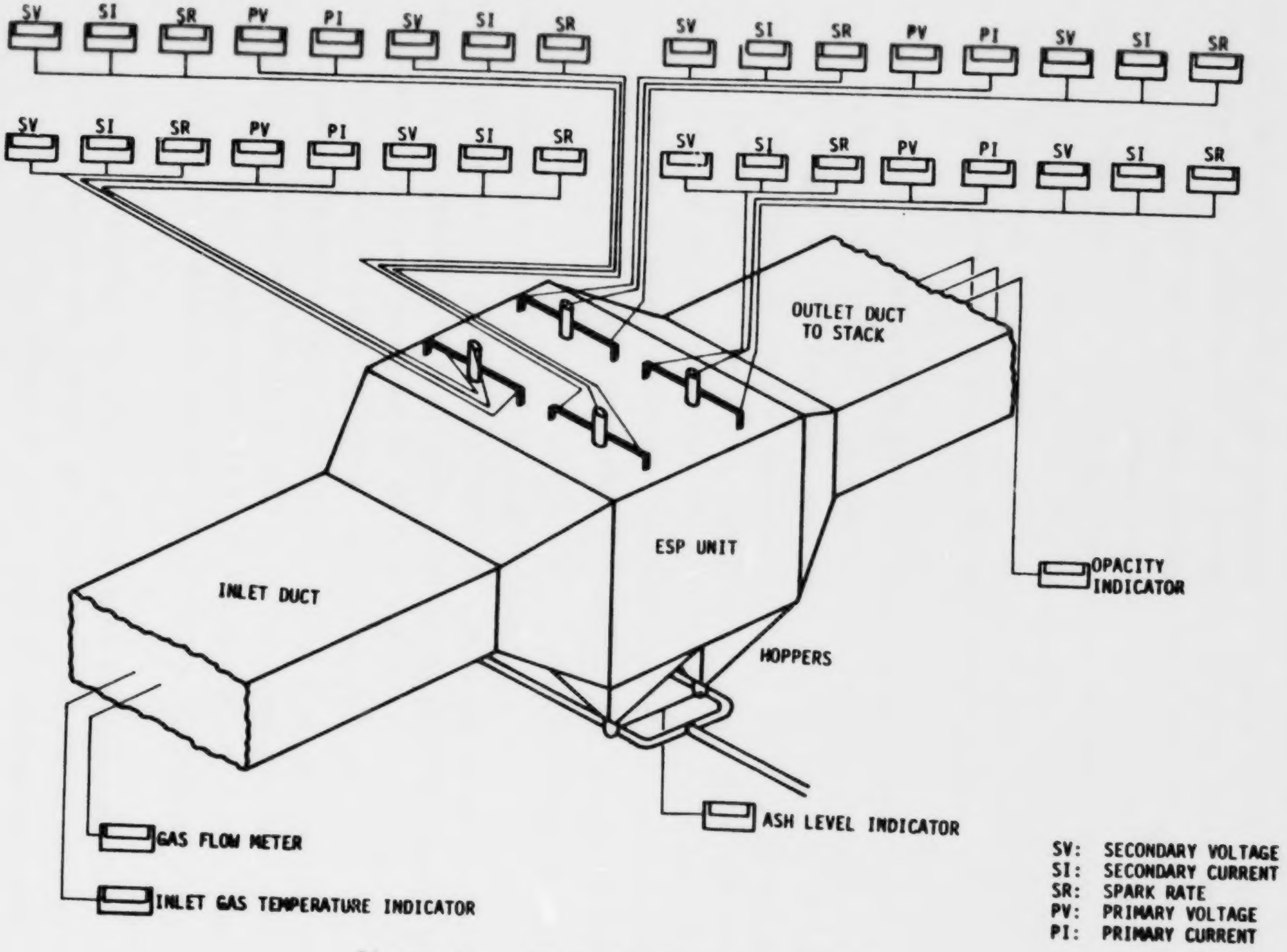
Electrostatic precipitator instrumentation includes monitors for power input, rapper intensity, and hopper dust levels. The power input parameters include precipitator current, voltage, and spark rate. The instrumentation is generally located close to the ESP unit. When a plant has more than one ESP, a centrally located control room may contain the instrumentation for all of the ESP units.

An ESP power supply usually includes several transformer-rectifier (T-R) sets, each having one or more bus sections. Primary voltage and current are measured for each T-R set; spark rate, secondary voltage, and current are measured for each bus section. Sometimes oxygen and temperature are measured at the ESP inlet. An opacity sensor is frequently located at the ESP outlet to indicate emission levels. The ESP shown in Figure 40 has four primary voltmeters and four primary ammeters. Instrumentation on the secondary side consists of eight voltmeters, eight ammeters, and eight spark rate meters.

Primary Instrumentation--

Most ESP's are equipped with a primary voltmeter, and normal operating voltage is 250 to 460 volts. An indication of zero voltage on the primary side may be due to an open primary circuit. An indication of high voltage on the primary is unlikely, but it could be due to an open transformer primary circuit or an improper connection. A faulty, open, or disconnected precipitator; an open.bus; or a faulty rectifier will also cause the primary voltage to be high. An indication of low voltage on the primary side could result from several conditions such as a leak in the high-voltage insulation, a high dust level in the hoppers, excessive dust on the electrodes, or swinging electrodes.

The ammeter on the primary side of the ESP indicates that the current is being drawn by the ESP. Together, the current and voltage readings on the primary side indicate the power input to a particular section of an ESP. Sometimes an ammeter is labeled to indicate the normal range of primary


SV
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SV
SI
SR
SV
SI
SR
PV
PI
SV
SI
SR
OUTLET DUCT
TO STACK
ESP UNIT
INLET DUCT
OPACITY
INDICATOR
HOPPERS
ASH LEVEL INDICATOR
GAS FLOW METER
INLET GAS TEMPERATURE INDICATOR
SV: SECONDARY VOLTAGE
SI: SECONDARY CURRENT
SR: SPARK RATE
PV: PRIMARY VOLTAGE
PI: PRIMARY CURRENT

Figure 40. ESP instrumentation diagram.

current, but the range is different for each unit, depending on design, size, and operating conditions. Baseline conditions established during a compliance test are a more reliable indication of proper operation. Any deviation from this range indicates abnormal operation. If the primary current and voltage are both zero, this indicates an open primary circuit. Low primary current combined with high primary voltage suggests an open transformer primary or secondary circuit. Low primary current and voltage indicate an open d.c. rectifier.

Irregular primary current coupled with low primary voltage indicates a high-resistance short in the circuit. Possible causes are an electrode short with dust in the hopper, excessive dust on collecting surfaces, excessive dust on electrodes, support insulator arcing, or the presence of foreign materials. A broken swinging electrode will cause an intermittent short, which is indicated by low primary voltage and cycling primary current.

Secondary Instrumentation--

Because primary instrumentation can be very misleading, the use of secondary meters is often more useful. Secondary instrumentation indicates the electrical parameters for individual bus sections. The instrumentation generally includes a kilovoltmeter, a milliammeter, and a spark rate meter for each bus section. The secondary voltmeter, which shows the voltage at the discharge electrodes, is sometimes labeled to indicate the normal operating voltage range. The indicated range may not be very reliable, however, and baseline conditions from a compliance test are probably a better indicator of proper operation. Zero voltage on the secondary may be due to an open primary circuit. High voltage on the primary side and no voltage on the secondary side indicate a faulty, open, or disconnected precipitator; an open bus; or a faulty rectifier.

Low voltage on the secondary side coupled with the low voltage on the primary side could result from several operating problems such as a leak in the high-voltage insulation, excessive dust in the hoppers or on the electrodes, or swinging electrodes. Correction may require shutdown.

The secondary ammeter indicates the discharge electrode current. The current and voltage readings on the secondary side indicate the power input to the discharge electrodes.

The secondary current is measured in milliamperes. The secondary ammeter is usually labeled to indicate the normal secondary current range. Deviation from that range indicates improper operating conditions in the precipitator. The absence of secondary current and voltage indicates an open primary circuit. Minimal secondary current in association with high voltage is generally due to an open transformer primary or secondary circuit. An open d.c. rectifier will cause a low current flow and low voltage in the circuit. As with primary circuitry, irregular secondary current coupled with low secondary voltage indicates a high-resistance short in the circuit. The short is usually caused by excessive dust, foreign materials, or arcing. Again, a broken swinging electrode causes an intermittent short, which is indicated by low voltage and cycling current. On coal-fired industrial boilers, the optimum spark rate is around 100 sparks per minute. Excessive sparking reduces available power for particle charging; a low spark rate indicates a reduction in power supply.

External Instrumentation--

Certain instruments external to the ESP that are useful for diagnosis of ESP operation include instruments that measure inlet gas flow, inlet gas temperature, and flue gas opacity at the ESP outlet. Instruments also monitor the condition of the hopper ash discharge system and the rapping system. Because federal and state regulations generally limit the opacity of the flue gases as well as particulate emissions, many ESP installations are equipped with continuous opacity recorders.

The gas flow rate and temperature are indicators of ESP loading. Variations from the normal design ranges will affect ESP performance and should be investigated.

Efficient removal of ash from the hoppers is important for proper ESP performance. Ash removal systems at ESP installations are generally equipped with instrumentation for monitoring hopper emptying cycles. Hopper level alarms are also common and useful. Control panel lights are used to indicate the operation of hopper heaters and vibrators. Zero motion switches may be used on rotary air-lock valves and on screw conveyors to detect malfunctions. Pressure switches and alarms may be used on pneumatic dust handling systems to detect operating problems.

3.3.4 Operation and Maintenance

The following subsections present ESP operating procedures and maintenance requirements and describe common ESP malfunctions. This information will help the inspector determine whether or not the company has an adequate maintenance program.

Power Supply--

During normal operation, the power to the ESP is optimized by automatic controls that vary the power in response to the spark rate.

Rappers and Vibrators--

The rapper system mechanically removes dust from the collecting plates. The most common system consists of magnetic-impulse, gravity-impact rappers that periodically impact the collecting plates to remove dust deposits. The main components of the system are the rappers and the electrical controls. The electrical controls provide separate adjustments for various groups of rappers; these can be independently adjusted from zero to maximum rapping intensity. The control cycles are adjusted to regulate the release of dust from the collecting plates and to prevent undesirable puffing from the stack.

During normal operation, a short-duration d.c. pulse through the coil of the rapper supplies the energy to elevate the steel slug. The slug is raised by the magnetic field of the coil and then allowed to fall back and strike an anvil bar connected to a bank of collecting electrodes within the precipitator. The shock transmitted to the collecting electrodes dislodges the accumulated dust. In some applications, the magnetic-impulse, gravity-impact rapper is used to clean the ESP discharge wires. For this purpose, the rapper strikes the electrode supporting frame in the same manner, except that an insulator isolates it from the high voltage of the frame. Some installations have mechanical rappers consisting of a single hammer assembly mounted on a shaft which raps each frame. A low-speed gear motor is linked to the hammer shaft by a drive insulator, fork, and linkage assembly. Rapping intensity is governed by the hammer weight, and frequency is governed by the shaft rotation speed.

A vibrating system can be used on either the collecting plates or the discharge wires to dislodge accumulations of particles. The vibrator is an electromagnetic device whose coil is energized by alternating current. Each time the coil is energized, the resulting vibration is transmitted through a rod to the high-tension-wire supporting frame or collecting plates (Figure 41). The number of vibrators depends on the number of high-tension frames or collecting plates in the system.

For each installation, a certain intensity and period of vibration will produce the best collecting efficiency. Low intensity will result in heavy buildup of dust on the discharge wires which reduces the sparkover distance between the electrodes. This limits the power input to the ESP and tends to suppress formation of the ions required for precipitation. Dust buildup also alters the normal distribution of electrostatic forces in the treatment zone and can lead to oscillation of the discharge wires and the high-tension frame. Because reentrainment from rapping can be a significant portion of the total emissions, it is important that the rapping system be adjusted to minimize reentrainment.

Maintenance Requirements--

At each ESP installation, the inspector should encourage the facility operator to follow a preventive maintenance schedule that lists the ESP parts to be checked and maintained daily, weekly, monthly, quarterly, and in specified situations. Such a schedule will help to ensure that the unit functions properly on a daily basis and that emission violations and opacity problems are minimized. Table 4 summarizes the maintenance procedures that the inspector can use to aid the source in setting up an effective preventive maintenance program.

3.3.5 Malfunctions

ESP equipment components are subject to failure or malfunction that can cause an increase in emissions. Malfunctions may be caused by faulty design, installation, or operation of the ESP, or they may involve electrical, gas flow, rapping, or mechanical problems. The inspector should be aware of the common ESP malfunctions, their effects on emissions, corrective actions, and preventive measures. Generally state and local control agencies require plant officials to report excess emissions that are caused by ESP malfunctions. Table 5 lists common ESP problems.

Monthly records of all malfunctions should be kept by plant and unit, along with total hours that T-R sets are operated, number of hours T-R sets

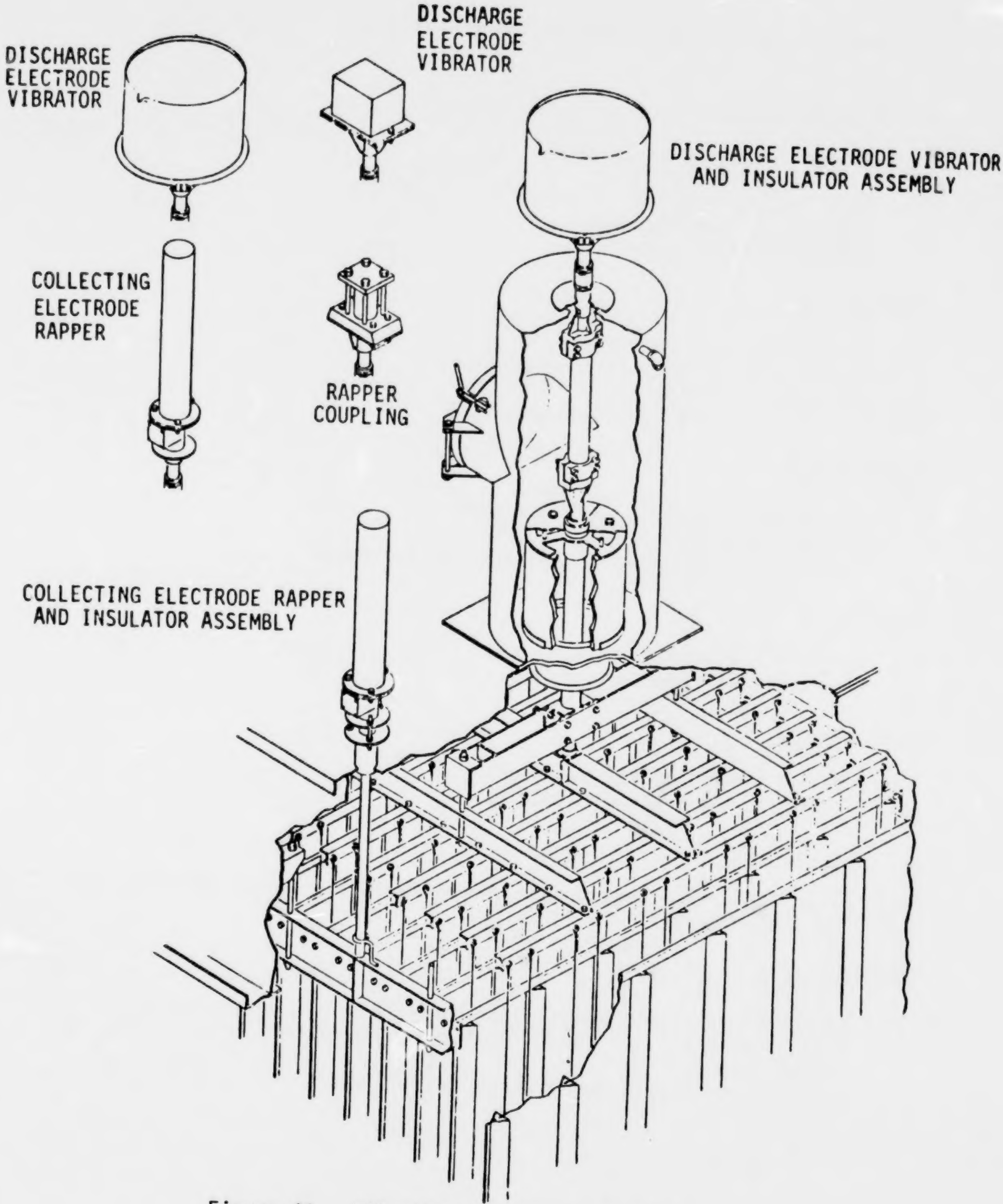

DISCHARGE ELECTRODE VIBRATOR
DISCHARGE ELECTRODE VIBRATOR
DISCHARGE ELECTRODE VIBRATOR AND INSULATOR ASSEMBLY
COLLECTING ELECTRODE RAPPER
RAPPER COUPLING
COLLECTING ELECTRODE RAPPER AND INSULATOR ASSEMBLY

Figure 41. Vibrator and rapper assembly, and precipitator high-voltage frame.

TABLE 4. MAINTENANCE SCHEDULE FOR ELECTROSTATIC PRECIPITATORS.

Enter on daily log

1. Boiler operating parameters
2. Flue gas analysis
3. Coal characteristics
4. T-R control set readings
5. Transmissometer calibration

Check daily

1. T-R control set readings
2. Rapper and vibrator control settings
3. Ash removal system
4. T-R control room ventilation system

Check Weekly

1. Operation of rappers and vibrators
2. Control sets (for internal dirt)
3. Air filters for control sets and ESP penthouse

Enter on weekly log

1. ESP voltage-current data
2. Graph ESP voltage-current data

Check monthly

1. Pressurization of ESP penthouse
2. Standby fan operation (manually)

Perform quarterly

1. Clean and dress contact surfaces of HW-FW electrical distribution.
2. Lubricate pivots.

Perform semiannually

1. Clean and lubricate access door hinges and test connections.
2. Inspect exterior for loose insulation, corrosion, loose joints, and other defects.
3. Check for points of gas leakage (in or out).

TABLE 4. (continued)

Perform annually

1. Thorough internal inspection:

   Check for possible leaks of oil, gas, or air at gasketed connections.
   Check for corrosion of any component.
   Check for broken or misaligned wires, plates, insulators, rappers, etc.
   Check high-voltage switchgear and interlocks
   Check all insulators and check for hairline cracks or tracking.
   Check expansion joints on hot ESP's.

2. Check for signs of hopper leakage, reentrainment of particulate, distribution plate blockage, and poor gas distribution.

3. Check for dust buildup in inlet and outlet flues.

4. Check for dust buildup in hoppers.

TABLE 5. SUMMARY OF PROBLEMS ASSOCIATED WITH ESP'S.

Malfunction	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Poor electrode alignment	Poor design Ash buildup on frame and hoppers Poor gas flow	Can drastically affect performance and lower efficiency	Realign electrodes. Correct gas flow.	Check hoppers frequently for proper operation..
Broken electrodes	Wire not rapped clean, causes an arc that embrittles and burns through the wire	Reduction in efficiency due to reduced power input, bus section unavailability	Replace electrode.	Boiler problems: check for insufficient excess air, insufficient pressure reading on gauges, fouled screen tubes, and fouled air preheater.
	Clinkered wire. Causes: poor flow area, distribution through unit is uneven; excess free carbon due to excess air above combustion requirements or fan capacity insufficient for demand required; wires not properly centered; ash buildup resulting in bent frame, same as above; clinker bridges the plates and wire shorts out; ash buildup, pushes bottle weight up causing sag in the wire; "J" hooks have improper clearances to the hanging wire; bottle weight hangs up during cooling causing a buckled wire ; and ash buildup on bottle weight to the frame forms a clinker and burns off the wire.			Inspect hoppers; check electrodes frequently for wear; inspect rappers frequently.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

(continued)

TABLE 5. (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Distorted or skewed electrode plates	Ash buildup in hoppers Gas flow irregularities High temperatures	Reduced efficiency	Repair or replace plates. Correct gas flow.	Check hoppers frequently for proper operation; check electrode plates during outages.
Vibrating or swinging electrodes	Uneven gas flow Broken electrodes	Decrease in efficiency due to reduced power input	Repair electrode.	Check electrodes frequently for wear.
Inadequate level of power input (voltage too low)	High dust resistivity Excessive ash on electrodes Unusually fine particle size Inadequate power supply Inadequate sectionalization Improper rectifier and control operation Misalignment of electrodes	Reduction in efficiency	Clean electrodes; gas conditioning or alterations in temperature to reduce resistivity; increase sectionalization.	Check range of voltages frequently to make sure they are correct. In-situ resistivity measurements
Back corona	Ash accumulated on electrodes causes excessive sparking, Requiring reduction in voltage charge.	Reduction in efficiency	Same as above	Same as above
Broken or cracked insulator or flower pot bushing leakage	Ash buildup during operation causes leakage to ground. Moisture gathered during shutdown or low-load operation	Reduction in efficiency	Clean or replace insulators and bushings.	Check frequently; clean and dry as needed; check for adequate pressurization of top housing.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

(continued)

TABLE 5. (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Air inleakage through hoppers	From dust conveyor	Lower efficiency - dust reentrained through ESP	Seal leaks.	Identify early by increase in ash concentration at bottom of exit to ESP.
Air inleakage through ESP shell	Flange expansion, improper sealing of inspection hatches	Same as above, also causes intense sparking	Seal leaks.	Check frequently for corrosion around inspection doors and for flange expansion.
Gas bypass around ESP: dead passage above plates and tension frame	Poor design - improper isolation of active portion of ESP	Only a small percent drop in efficiency unless severe	Baffling to direct gas into active ESP section	Identify early by measurement of gas flow in suspected area. around high
Corrosion	Temperature goes below dew point.	Negligible until precipitation interior plugs or plates are eaten away; air leaks may develop causing significant drops in performance.	Maintain flue gas temperature above dew point.	Energize precipitator after boiler system has been on line for ample period to raise flue gas temperature above acid dew point.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

(continued)

TABLE 5. (continued)

Malfunctions	Cause	Effect on ESP Efficiency[a]	Corrective action	Preventive measures
Hopper pluggage	Wires, plates, and insulators fouled because of low temperature Inadequate hopper insulaton Improper maintenance Boiler leaks causing excess moisture Ash-conveying system malfunction - gas leakage - blower malfunctions - solenoid valves Misadjustment of hopper vibrators Material dropped into hopper from bottle weights Solenoid and timer malfunction Suction blower filter not changed	Reduction in efficiency	Provide proper flow of ash.	Frequent checks for adequate operation of hoppers; Provide heaters and/or thermal insulation to avoid moisture condensation.
Inadequate rapping, vibrators fail	Ash buildup Poor design Rappers misadjusted	Resulting buildup on electrodes may reduce efficiency.	Adjust rappers with optical dust measureing instrument in ESP exit stream.	Frequent checks for adequate operation of rappers
Too intense rapping	Poor design Rappers misadjusted Improper rapping force	Reentrains ash and reduces efficiency	Same as above	Same as above; reduce vibrating or impact force.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

(continued)

TABLE 5. (continued)

Malfunctions	Cause	Effect on ESP efficiency[a]	Corrective action	Preventive measures
Control failures	Power failure in primary system Transformer or rectifier failure: insulation breakdown in transformer arcing in transformer between high-voltage switch contacts leaks or shorts in high-voltage structure insulating field contamination	Reduced Efficiency	Find source of failure and repair or replace.	Pay close attention to daily readings of control room instrumentation to spot deviations from normal readings.
Sparking	Inspection door ajar Boiler leaks Plugging of hoppers Dirty insulators	Reduced efficiency	Close inspection doors; repair leaks in boiler; unplug hoppers; clean insulators.	Regular preventive maintenance will alleviate these problems.

[a] The effects of precipitation problems can only be discussed on a qualitative basis. There are no known emission tests of precipitators to determine performance degradation as a function of operational problems.

are not operating, maximum number of sets out at one time, and monthly/yearly availability of the ESP unit. Daily logs should be kept for each ESP, with remarks on outages in each section of the ESP.

3.3.6 Inspection Procedures

Data Collection and Review of Operating Records--

The inspector should review both process and ESP operating records for completeness and for changes in operation that may have affected ESP performance. Table 6 lists a number of items for which records should be kept. Malfunctions of both the process and the ESP should be discussed with plant officials, and the inspector should determine what is being done to remedy any recurrent problems.

The first item that the inspector should check is the control sets for the ESP, which are usually located in a room near the ESP. Plant personnel should provide a diagram showing which fields are served by which T-R sets, as a guide for determining out-of-service fields when reading the T-R sets. Control panels can include primary and secondary current and voltage meters, and a spark rate meter. If the ESP has several sections, the voltage, current, and spark rate should be recorded for each section. The control set readings should be compared with calibrated or design values for each section. The inspector should check the daily log of control readings to determine whether the readings have been drifting from normal. Drift may indicate such problems as air leakage into air heaters or into ducts leading to the ESP, dust buildup on ESP internals, and/or deterioration of electronic control components. The inspector should also note inoperative meters, the number of power supplies on manual control, and T-R sets on automatic control that may be operating below design specifications to reduce wire breakage.

The inspector can utilize the meters to aid in diagnosing other ESP problems. The effects of fluctuating gas conditions on control readings are presented below:

1. The voltage increases and the current decreases when the gas temperature increases. Arcing can also develop. The voltage decreases and the current increases when the gas temperature decreases.

TABLE 6. RECOMMENDED RECORDKEEPING REQUIREMENTS.

	Frequency	Comments
ESP		
Controls		
Instrument calibration	Initial measurement	Compare daily measurements with redlined readings. Check for gross misreadings or slow drift from redline.
Primary current, A	Daily	
Primary voltage, V	Daily	
Operating current, mA	Daily	
Operating voltage, kV	Daily	
Spark rate, sparks/min	Daily	
Pressure drop through system, in.	Daily	Compare with initial pressure
Rapper operation	Daily	Check frequency and intensity
Insulator condition	Daily	Check for deterioration
Hoppers	Daily	Level alarms, evacuation system
BOILER		
Fuel quality	Monthly	State range of values and average
Sulfur, %		
Ash, %		
HHV, Btu/lb		
Recording instrumentation		
Fuel flow-air flow control	Daily	Maintain circular charts for 3 months
Steam flow-air flow control	Daily	Maintain circular charts for 3 months
Changes in boiler operation	As occurring	
Flue gas analysis, % by vol. (Circle CO_2 or O_2)	Spot checks	
Soot blowing intervals	Daily	State hours or blows per day
Malfunctions (boiler or ESP)	As occurring	Use standard form to describe malfunctions

2. The current and voltage increase when the moisture content of the gas increases for any given condition.

3. The voltage increases and the current decreases when there is an increase in the concentration of the particulate matter.

4. The voltage increases and suppresses current when there is a decrease in the particle size.

5. The voltage increases and depresses current when there is a higher gas velocity through the ESP.

6. Reduced voltage may be caused by air inleakage that causes sparkover in localized areas.

7. A number of ESP fields in series will show voltage-current ratios decreasing in the direction of gas flow.

8. The voltage is drastically reduced and the current increases when a hopper fills with dust and causes a short.

9. Violent arcing, indicated by the meters swinging between zero and normal, occurs if a discharge electrode breaks.

10. The voltage drops to zero at a high current reading if a T-R unit shorts.

11. A voltage increase with normal current levels occurs if a discharge rapper fails and the discharge wires build up with dust.

12. A voltage decrease with normal current levels under sparking conditions occurs if a plate rapper fails.

Table 7 presents specific examples of the effect of changing conditions on ESP control set readings. These examples are typical of what the inspector may find. The inspector should become familiar with these meter reading techniques so as to detect problems during an inspection.

Electrical Equipment--

The T-R sets, rappers, and/or vibrators are often located on top of the ESP in the penthouse. The control sets are most commonly found in the boiler control room. The T-R sets, insulators, and rapper/vibrators should be inspected.

The inspector should examine insulators for moisture and cracking from arc-over. Cracks can be spotted with a bright light during inspection. Corrosion of the insulator compartment is another indication of moisture buildup.

TABLE 7. EFFECTS OF CHANGES IN NORMAL OPERATION ON ESP CONTROL SET READINGS.

Condition	Effect	Primary voltage V, a.c.	Primary current A, a.c.	Secondary current mA, d.c.
1. Normal full load		300	50	200
2. System load fall by 1/2	Gas volume and dust concentration decrease, resistance decreases	260	55	230
3. System load constant, but increase in dust load	Resistance increases	350	40	175
4. Gas temperature increases	Resistance rises, sparking increases because of increased resistivity	300-350	50-60	20-250
5. Gas temperature decreases	Resistance decreases	280	52	210
6. ESP hopper fills with dust	Resistance decreases	180	85	300
7. Discharge electrode breaks	Resistance may fall to 0 (may vary between 0 and normal if top part of electrode is left swinging inside the ESP). Violent instrument fluctuations, Arcing can be heard outside the ESP	0-300	0-50	0-200
8. Transformer-rectifier shorts	No current passes from T-R set to the ESP	0	100+	0
9. Discharge system rapper fails	Dust builds up on discharge electrodes. Resistance increases because corona discharge decreases. Additional voltage required to keep current constant	330	50	200
10. Collection plate rapper fails	Sparking increases. Voltage must be reduced to keep current constant	265	50	200

The inspector should check to see that the pressurization fan for the top housing or insulator compartment is operating properly, and that air filters for control sets and the top housing are not plugged. The condition of access hatch covers should also be noted.

The inspector should check rapper and vibrator action visually and/or by feel. A uniform rhythmic tapping of metal to metal characterizes rappers; vibrators emit a loud buzzing sound. Any irregular sounds may indicate improper rapper or vibrator operation. The plant should provide a diagram of the rapping system sequence so that the inspector can verify that all of the rappers or vibrators are operating properly. Rapping intensity should be checked against design, and any indication of reduced rapping intensity should be questioned.

ESP Housing--

The inspector should examine the exterior of the ESP housing for corrosion, loose insulation, exterior damage, and loose joints. The ducts entering the ESP should be checked; if they show corrosion, the interior of the ESP also may be corroded. The inspector should check for fugitive emissions (with positive pressure systems) or air inleakage (with negative pressure systems) at loose joints and as a result of other exterior damage.

Ash Handling System--

The inspector should check to see that the evacuation rate for the ash hoppers prevents ash accumulation. Inlet field hoppers, for example, normally collect 60 to 80 percent of the total catch and must be emptied much more often than the downfield hoppers. If level alarms are used, the inspector should ensure that they are operating properly.

The inspector should look for problems in the ash evacuation and removal system, including water pump failure (a water pump may be used to create the vacuum), vacuum line disconnections, rotary air lock malfunctions, and sequencing control failures.

If ash is removed from a collection silo by truck, the inspector should ensure that the truck fill pipe extends far enough into the truck to minimize fugitive emissions.

Process Instrumentation--

After finishing with the ash handling system, the inspector should check a number of process parameters that can affect ESP performance. For example, readings of gas flow, gas velocity, excess air, gas temperature, pressure drop, moisture, flue gas analysis, soot blowing intervals, and opacity should be taken if possible. Many instruments in the boiler control room have continuous readouts. Figure 42 shows an example trace from a continuous opacity monitor. Variations in process readings from the normal design ranges should be investigated in conjunction with ESP control set readings and visual observations made during the inspection for possible effects on ESP performance.

Internal Inspection--

If an ESP is down for scheduled maintenance or because of a malfunction during an inspection, the inspector should take time to check inside the unit and observe the dust accumulation on plates and wires. (Note: Be sure and follow proper safety procedures described on Pages 129 or 132.) The discharge wires should only have a slight coating of dust, with no corona tufts (doughnut-shaped ash accumulations). Thickness of dust buildup on plates is normally between 0.3 and 0.6 cm (1/8 to 1/4 in.). If the plates have more than 0.6 cm (1/4 in.) of dust, the rappers are not cleaning properly. If the collecting plates are almost metal clean, this may be an indication of high gas velocity, extremely coarse fly ash, too high a rapping intensity, or too low an operating voltage for good precipitation. The inspector may notice this if a section has been shorted out prior to the inspection.

The inspector should note whether or not the discharge electrodes are centered between the collecting plates from top to bottom to ensure optimum performance. Also any broken or missing discharge electrodes should be noted. The company should keep records of wire breakage to help determine if multiple wire breaks in the same area may be due to alignment problems. Random wire breakage is probably caused by dust buildup on wires or plates.

The inspector can check for air inleakage from door openings by noting the amount of corrosion on collecting plates adjacent to inspection hatches, and from the hoppers by checking on the lower portion of the collecting plates. Air inleakage also causes nonuniform gas flow which can reduce ESP efficiency.

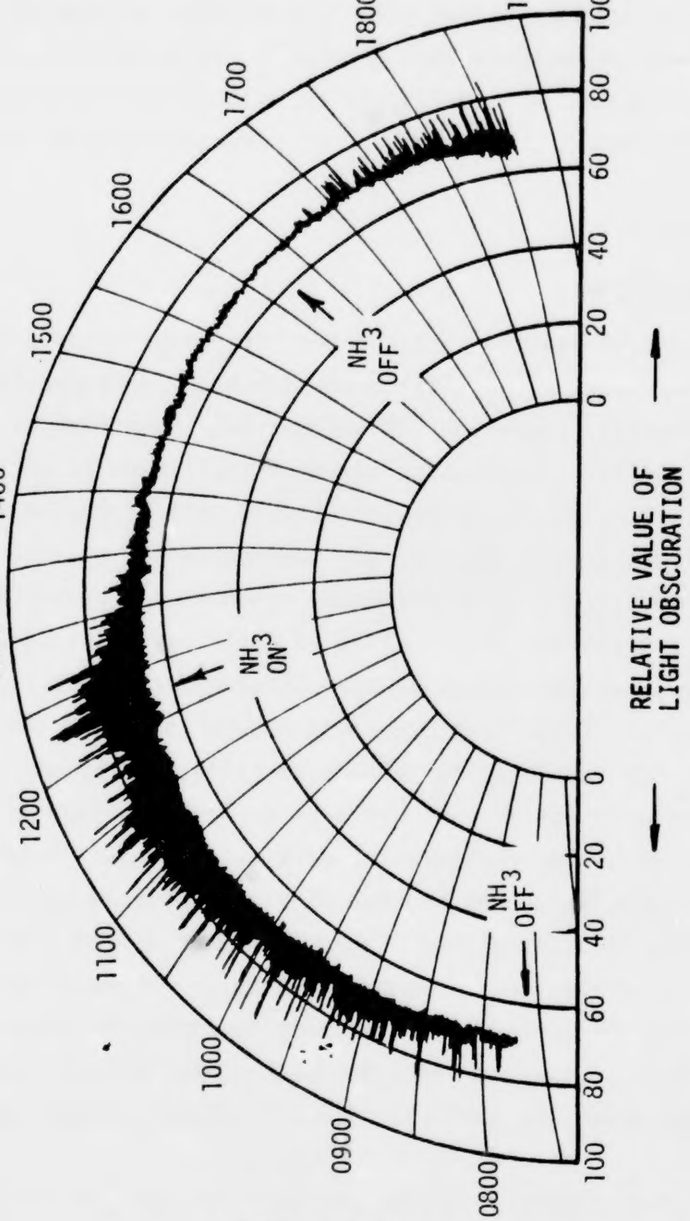


Figure 42. A sample opacity chart.

The inspector should have plant personnel open the hopper access door and then check for corrosion, which indicates air inleakage as mentioned previously. He/she should check for dust buildup in the upper corners of the hopper and for debris, such as fallen wires and weights, within the hoppers. If discharge electrode weights have dropped 3 inches or more, this indicates a broken wire. Chronic ash buildup is an indication of low operating temperatures, insufficient heat insulation, or inadequate hopper emptying.

3.4 SCRUBBERS

3.4.1 Introduction

Wet scrubbers capture particulates into either liquid droplets, sheets, or jets. The principal physical mechanism used in commercially available systems is inertial impaction. Other physical phenomena aiding capture include Brownian diffusion (random movement that leads to particulate capture), diffusiophoresis (particle migration toward site of condensation due to differences in mass concentration), and thermophoresis (particle movement toward colder temperature due to differences in momentum transferred in molecular collisions). Diffusion only applies to small particles of about 0.05 µm. Unfortunately, neither impaction nor diffusion is very effective for 0.1- to 1-µm diameter particles that are small enough to follow gas streamlines around the droplets but too large for effective collection by diffusion. Figure 43 illustrates the effect of particle size on impaction and diffusion.

Some boilers use scrubbers for particulate emission control, but scrubbers are not generally used because of high operating costs. A scrubber is more practical for controlling particulate matter from a spreader-stoker boiler than from a pulverized-coal-fired boiler because the stoker boiler produces larger particles and relatively low mass loadings. Pressure drop, water flow rate, suspended and dissolved solids, plugged and eroded pipes and nozzles, pump wear, and particle size all affect scrubber particulate removal efficiency.

Particulate scrubbers types include: impingement plate, centrifugal spray, self-induced spray, disintegrator, moving bed, ejector, foam, and venturi. Centrifugal scrubbers are frequently found on stoker boilers; venturi scrubbers are more commonly used on pulverized-coal-fired boilers.

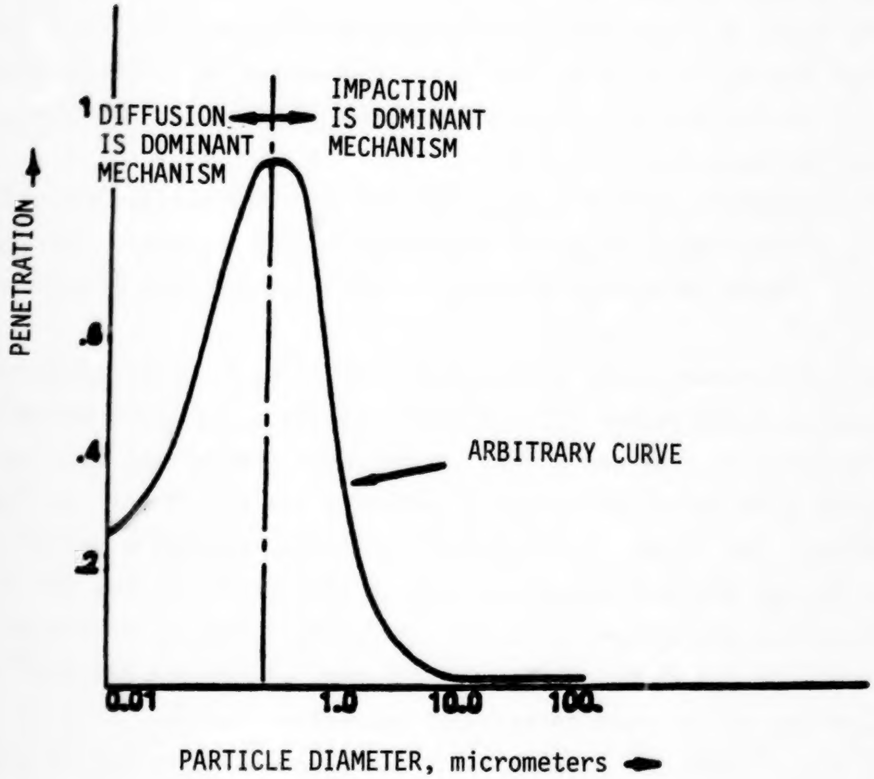


Figure 43. Importance of particle size on wet scrubber penetration.

Impingement scrubbers use perforated or slotted plates containing target plates opposite all openings to cause an abrupt change in direction (and acceleration) of contaminant laden air (see Figure 44). When flooded with scrubbing liquid, these designs produce a high surface area froth of scrubbing liquid on its top surface and turbulence, both of which contribute to particulate removal and gas absorption.

A spray tower is a gas absorption device developing high liquid surface areas through the use of a spray nozzle(s), hydraulically or pneumatically atomized. It is not very effective at removing particulates and rarely used on industrial boilers (see Figure 45).

Dynamic scrubbers utilize a fan, impeller or other motive device to mechanically produce small droplets which enhance gas absorption and particulate removal. These are typically sprayed fans, coupled with droplet removal devices.

Moving bed scrubbers were developed primarily as an alternative to packed bed scrubbers in applications with both particulate and gaseous contaminants. As shown in Figure 46, the gas enters at the lower side of the unit and passes upward through a series of beds each of which is 10% to 25% full of lightweight packing. The liquor is introduced at the top through a set of nozzles and passes through the beds countercurrent to the gas flow. The bed is fluidized by the moving gas stream; this results in the formation of liquid droplets and sheets in the turbulent zone of the bed. A chevron demister or equivalent serves as the main entrainment separator.

A cyclonic scrubber is a spray tower variation in which gas is spun cyclonically in a vessel with scrubbing liquid sprayed concurrently into the stream (see Figure 47).

In the venturi scrubber the boiler exhaust gas and entrained particulate matter are accelerated to a high velocity in the venturi throat. The high gas velocity shatters the water in the scrubber and forms small water droplets that provide impact targets for the particles. The particles collide with the water droplets and stick to them, agglomerating into larger droplets that are then fairly easy to remove from the gas stream. High throat velocities, high liquid-to-gas ratios, and resulting high pressure drops through a scrubber enhance efficiency.

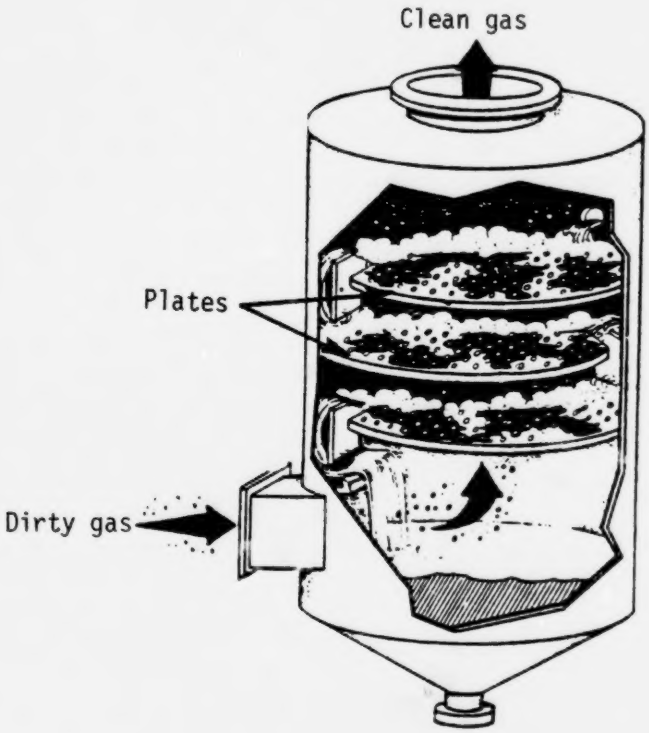

Clean gas
Plates
Dirty gas

Figure 44. Tray scrubber.

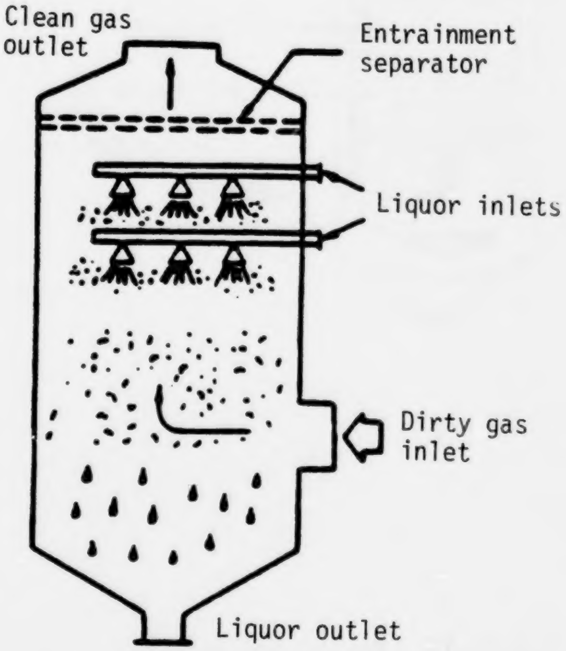

Clean gas outlet
Entrainment separator
Liquor inlets
Dirty gas inlet
Liquor outlet

Figure 45. Spray tower.

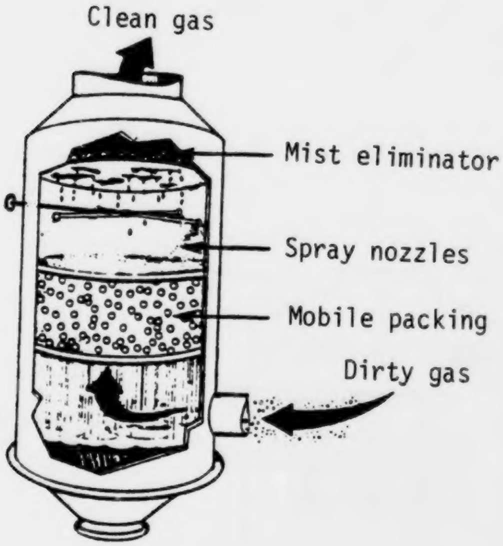

Clean gas
Mist eliminator
Spray nozzles
Mobile packing
Dirty gas

Figure 46. Moving Bed Scrubber.

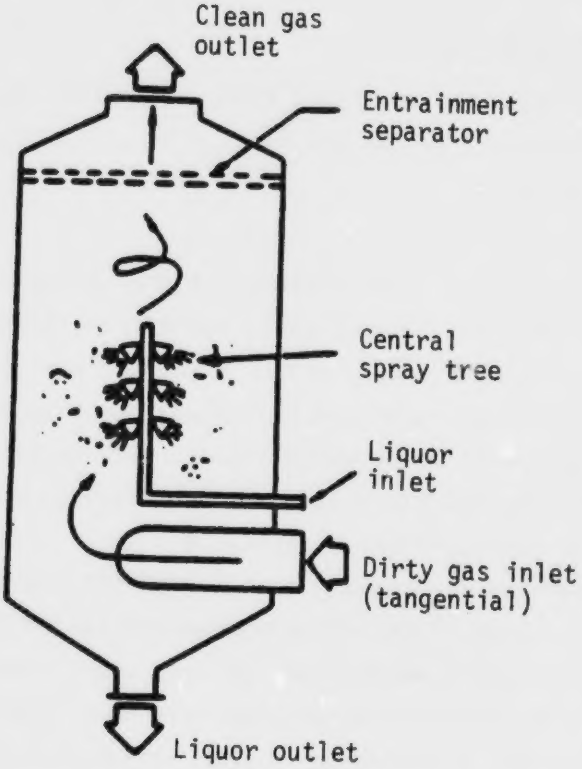

Clean gas outlet
Entrainment separator
Central spray tree
Liquor inlet
Dirty gas inlet (tangential)
Liquor outlet

Figure 47. Cyclonic spray tower.

Typical venturi scrubbers (see Figures 48 and 49) are made of 316 stainless steel. Most designs use a flooded elbow and a variable throat to control pressure drop. The flooded elbow provides a trough of water to capture the larger water droplets and particulate matter that exit the scrubber and to prevent abrasion of the elbow at the turn. The venturi throat may be circular, rectangular, or oval; the throat area is changed by moving hinged plates, a bob, or some other surface inside the venturi to control the pressure drop. Water is introduced into the scrubber immediately ahead of the venturi throat. Venturi scrubbers are more compact and versatile than the other types, and they cost less than other scrubbers of comparable efficiency.

3.4.2 Operation and Maintenance

Most scrubber problems involve liquid flow, corrosion and erosion, scaling and plugging, entrainment, and/or gas flow. These problems are described in the paragraphs which follow.

Liquid Flow--

Common problems with liquid flow include build-up at the wet-dry interface, poor liquid distribution, loss of seal, and malfunctioning pumps.

If the scrubber design improperly allows dry dust laden gas to contact the juncture of the scrubbing liquid and the vessel, dust build-up will occur. Good designs prevent this contact by extending ductwork sections sufficiently into the scrubber and by thoroughly wetting all scrubber surfaces through a reliable method such as gravity flush or sprays.

The gas and liquid must be properly distributed for the given application. Improperly distributed flows can be aggravated by the influence of baffles (needed or accidental), mechanical failure, wear, scaling in headers, or improper design. Flow distribution problems are most common in packed and spray towers. The swirling of scrubbing liquid, especially on cyclonic devices, can cause severe wear and draining problems unless arrested by antiswirl plates in the scrubber or rapid continuous draining.

Most scrubbers operate near atmospheric or ambient conditions. A pump recirculates the scrubbing medium, and a liquid seal prevents pump cavitation. This seal may be at the top of a quencher or from an overflow connection. Loss of seal can cause entrainment or plugging and instrumentation malfunction.

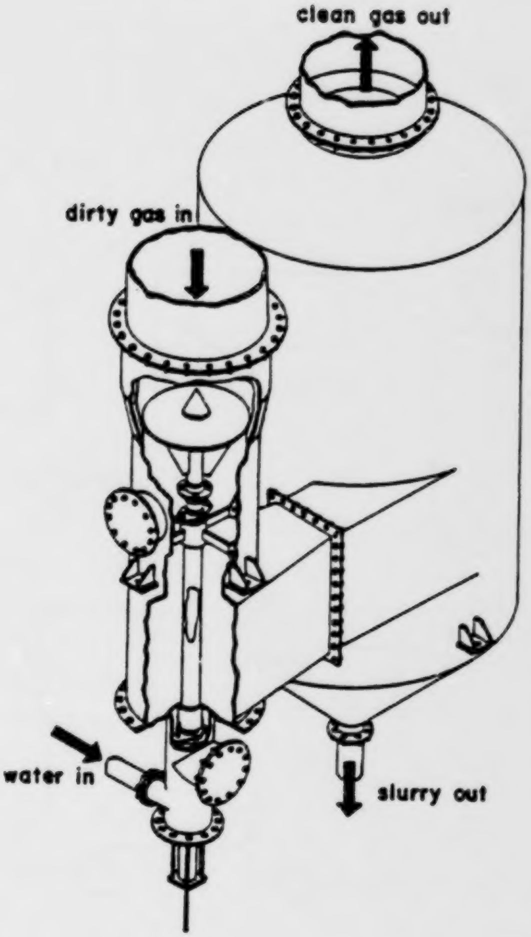

clean gas out
dirty gas in
water in
slurry out

Figure 48. Bob type venturi scrubber.

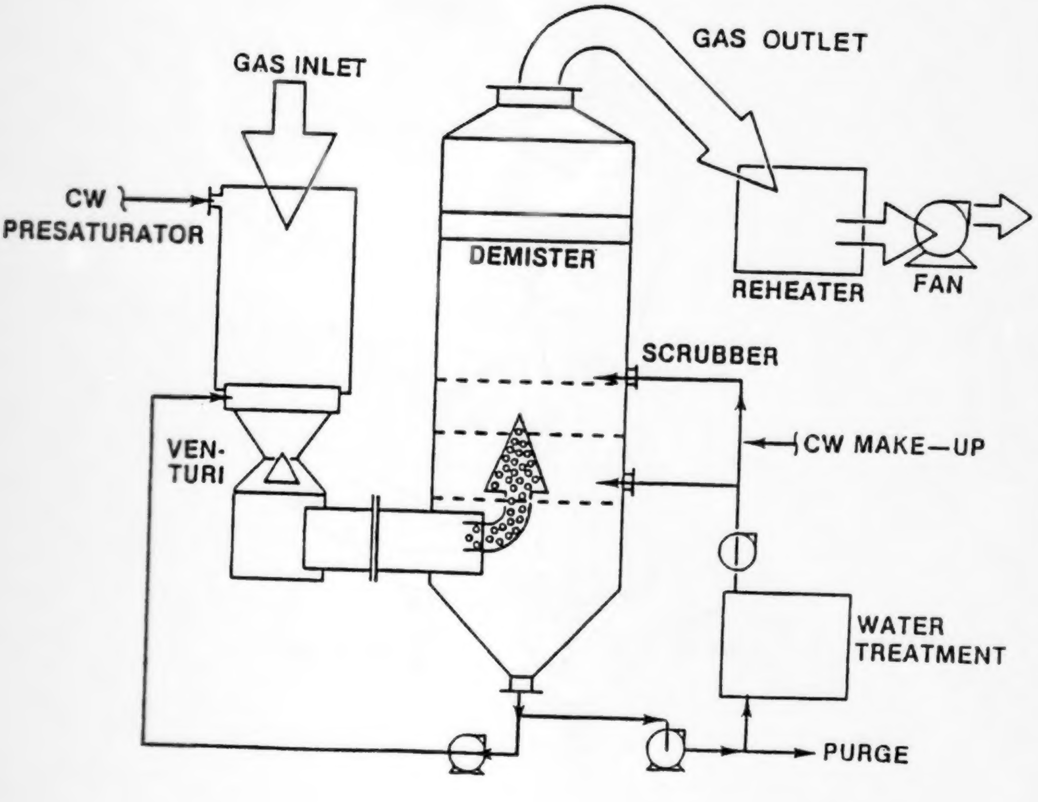

GAS INLET
GAS OUTLET
CW
PRESATURATOR
DEMISTER
REHEATER
FAN
SCRUBBER
VEN-
TURI
CW MAKE—UP
WATER
TREATMENT
PURGE

Figure 19. Venturi scrubber components.

Accelerated wear of the centrifugal pump impeller occurs at high suspended solids (flyash) levels. The best way to minimize scrubber downtime due to pump malfunctions is to minimize the total quantity of suspended solids, especially the larger suspended particles (greater than 25 micrometers). A clarifier or centrifugal separator can improve the quality of liquor passing through the pump by reducing suspended particle loadings.

Corrosion and Erosion--

Corrosion is a major factor in shortening the operation life of a scrubber whether properly designed or not. Wells or pockets of liquid should be avoided and points of stress should be adequately flushed. Relatively small levels of chlorides and fluorides can attack many types of materials, especially the 300 series stainless steels. Internal members usually should be thicker than the shell.

It is important to maintain the pH of the scrubbing liquid well above the levels at which carbon steel (the most common material used in scrubber construction) is attacked. A pH of 6 or greater is usually satisfactory. Otherwise, FPP or expensive nickel/chrominum alloys such as Hastelloy must be used. Maintenance of an appropriate pH is usually accomplished through the use of alkaline additives such as soda ash, lime, or limestone. If a pH of 6 or greater is maintained, significant sulfur dioxide removal (greater than 75%) will occur. The operation of the pH monitor used to control the rate of additive injection should be checked at least on a daily basis unless long term operating experience justifies a less frequent inspection. A portable pH meter or pH paper can be used for this check. It is preferable to obtain a sample from the sump of the scrubber since this is often the point of minimum pH.

The recirculation rate is an important factor in determining the extent to which halogenated compounds are building-up in the scrubbing liquid.

One convenient means to monitor potential corrosion problems is to prepare small coupons (small circular samples) of the various materials used throughout the scrubber system. These are placed in racks which can be mounted at various locations in the scrubber. During every outage these are visually inspected for pitting and cracking and are weighed for material loss. This information provides an early indication of developing corrosion problems.

The scrubber is susceptible to erosion due to high velocities of the liquid stream and suspended solids within the stream. High gas stream velocities can also lead to erosion. Venturi throats on venturi scrubbers are subject to velocities as high as 20,000 to 40,000 feet per minute. Other high wear areas are those which inhibit gas flow such as elbows and gas distribution structures.

Nozzles are also susceptible to erosion. Using special ceramics and reducing the scrubbing liquid solids content can minimize problems. Some nozzle designs, such as those that include an internal spinner vane, can lead to accelerated erosion. Deluge-type nozzles or nozzles without internal structures are least susceptible to erosion.

Scaling and Plugging--

Scaling is the plating out of deposits on a scrubber surface. Usually it is harmless unless the scrubber part cannot function because of the deposit. Scaling is caused by interactions of the chemical composition, solubility, temperature, and pH of the scrubbing liquid. It is a difficult problem to diagnose; a good deal of research has been done on calcium-based SO_2 scrubber scaling problems.[7] Proper control starts with the scrubber design and process control.

Spray nozzles are extremely susceptible to plugging problems due to the high liquid stream velocities and suspended solids content. The most common types of nozzles in use include the hollow cone and the full cone. The latter is particularly prone to pluggage due to the presence of an internal spinner vane. The vane is installed to achieve the full cone spray pattern which is necessary for distribution of liquor on a moving bed scrubber. Improper header design allows particles to settle which may plug nozzles. Centrifugal separators can be used to remove particles before they reach the nozzles. Scale problems can also be solved by separators, but proper control of scrubber chemistry is a better approach.

Instrument lines can become blocked from particle settling or scale deposits. Specially designed instrument fittings and connections may be required for use with scrubbers. Instrument probes in continuously circulating loops have less blockage problems than probes in dead-ended lines.

Mist Entrainment--

Entrainment occurs when the droplet separator is not functioning properly. Nearly all scrubbers have some entrainment losses. A properly designed system can eliminate entrainment carryover. Droplets impinge on eliminator surfaces and return to the scrubber. Figure 50 shows two types of mist eliminators.

Gas Flow--

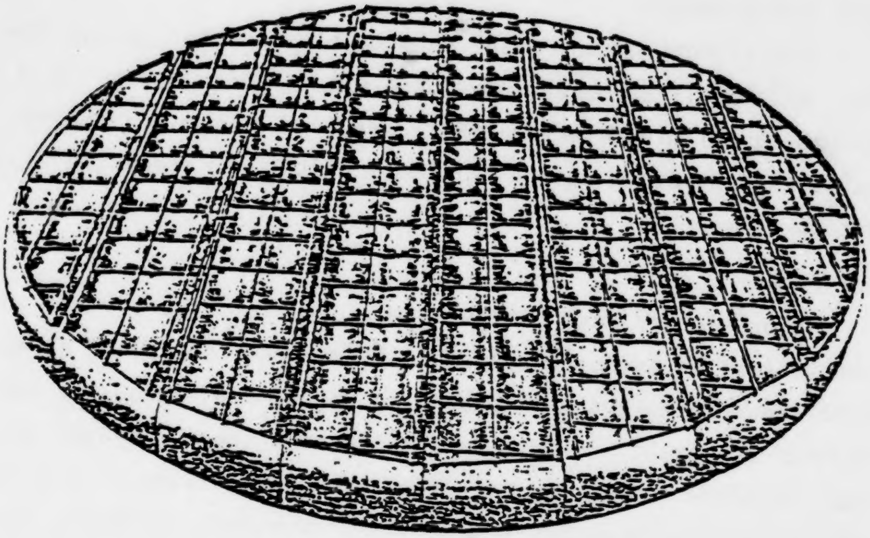
Vibration is most common in wet dynamic scrubbers and in the fans on wet fan venturi or cyclonic systems. It is best controlled by monitoring and scheduled preventive maintenance to remove scale deposits and to lubricate and balance equipment. Fan vibration can sometimes be caused by air flow factors and, in these cases, can be eliminated by adjusting or modifying the inlet or outlet dampers or modifying the inlet or outlet ductwork. Even gas distribution through the scrubber is important to obtain maximum particle wetting and collection. Gas maldistribution can be checked with pressure gauges and can be eliminated by using inlet baffles or gas distribution plates, by adjusting inlet dampers, and by proper scrubber design that eliminates gas bypasses.

If the gas stream entering the scrubber is very hot (greater than 300°F), it is often desirable to cool the gas stream. This protects the scrubber materials of construction, especially corrosion and abrasion resistant linings, from thermal shock and degradation. Gas stream cooling can be accomplished in evaporative coolers or presaturators. Multiple cooling zones may be necessary for large temperature differences.

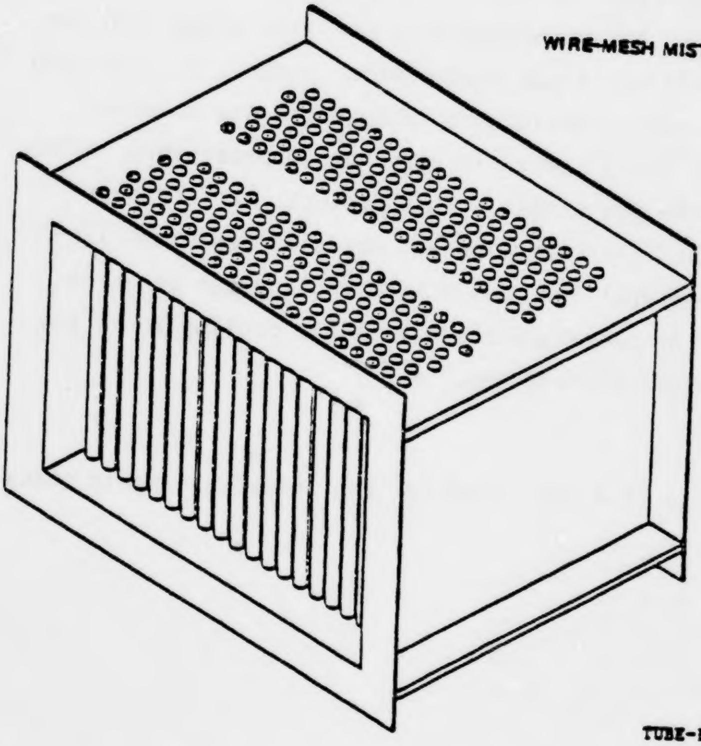
3.4.3 Inspection Procedures

To evaluate the performance of a wet scrubber, the inspector should check the following areas:

- Liquid circulation,
- Gas flow,
- Gas pressure drop,
- Liquid pH,
- Scrubber corrosion, and
- Nozzle and shell erosion.



WIRE-MESH MIST ELIMINATOR



TUBE-BANK MIST ELIMINATOR

Figure 50. Mist eliminators.

The recirculation pump and fan should be operating. If there is no scrubber liquid circulating through the system or the flue gas is being bypassed, the inspector should recommend a follow-up inspection when the scrubber will be operational. If there is circulation, the inspector should follow the liquid flow through the system (liquid flow is generally counter to gas flow).

Next, the inspector should confirm that the pumps are on, and if so, the inspector should read the flow meter (if any). In the line going to the spray nozzles, low pressure indicates erosion of the nozzles and likely increases in the water spray droplet size. If the line pressure does not change when the flow is temporarily shut off (the inspector must not adjust valves), the nozzles are plugged. Localized higher shell temperatures (5 to 10°F above normal) also indicate an area with plugged nozzles. If possible, static pressure drop across each stage should be recorded to help in problem diagnosis.

To complete the check of the liquid system, the inspector should measure the temperature and the pH of the sump liquor. It is advisable to take a liquor sample; however, the expense should not be incurred unless there are reasons to suspect operational and/or corrosion problems (chain-of-custody procedures must be followed). During the inspection, the corrosion and erosion of the scrubber shell (look for holes) and component parts should be routinely checked.

SECTION 4

GENERAL PREPARATORY AND PRE-INSPECTION PROCEDURE

To conduct a successful inspection of an industrial power plant requires careful preparation. Such preparation includes:

- Becoming familiar with the boiler and its control equipment,
- Reviewing past operating practices,
- Procuring and testing the necessary inspection equipment to be sure it is working properly,
- Inspecting the plant's exterior to obtain information about operating practices, and
- Advising key plant personnel well in advance so that they are available to answer questions and take part in the inspection. (The cooperation of key plant personnel is critical to the success of the inspection.)

Advanced preparation on the part of the inspector can save valuable time, both for the inspector and for plant personnel. A well-informed and prepared inspector generates a degree of confidence that makes plant personnel more inclined to provide information critical to completing a comprehensive compliance assessment.

4.1 FILE REVIEW

A logical starting point for Agency inspectors is a review of the plant's file. The following items should be checked, and copies of the first two items in the following list should be obtained from the inspection files.

- Pending compliance schedules;
- Construction and/or operating permits pertaining to source processes;
- Past conditions of noncompliance;

- Malfunction frequency and causes; and
- History of abnormal operations.

The inspector should also obtain a copy of the overall plant layout drawings, and these should be reviewed before plant entry.

The inspector should prepare a concise file containing basic plant information, process descriptions, flowsheets, and acceptable operating conditions. This file should also contain the following to facilitate the inspection:

- A chronology of control actions, inspections, and complaints concerning each major source in the plant,
- A flowsheet identifying sources, control devices, monitors, and other information of interest,
- All permits for each major source, and
- Previous inspection checklists.

Based on available information, the inspector should select a time for the inspection when processes are likely to be operating at representative conditions. This is especially important for plants with batch operations or other irregular operating schedules (e.g., seasonal).

The inspector should carry the following tools and safety gear for all inspections:

- Hard hat,
- Safety glasses or goggles,
- Gloves,
- Coveralls,
- Safety shoes (steel-toed),
- Ear protectors,
- Tape measure,
- Flashlight,
- Manometer or differential pressure gauges,
- Stopwatch,

- pH paper,
- Duct tape, and
- Pocket guide of industrial hazards.

Safety equipment is particularly important. It is the inspector's responsibility to have safety equipment before entering the plant. Access to certain industrial facilities may be legally restricted or refused by plant representatives if the inspector is not wearing the designated equipment.

The following equipment can be left in a central location and only carried to the source when needed:

- Pipe wrench,
- Respirator with appropriate cartridge(s),
- Velocimeter,
- Pump and filter system,
- Bucket,
- Combustion gas analyzer,
- Thermometers or thermocouples,
- Multimeter,
- Sample bottles,
- Strobe,
- Inductance ammeter,
- Tachometer,
- Oxygen and combustibles meter,
- Self-contained breathing equipment, and
- Rope.

A uniform inspection procedure helps both the source operators and regulatory agency inspectors in the routine evaluation of the performance of air pollution control equipment. The fundamental principle of the procedure is that performance is diagnosed by comparing observed operating conditions at the site with baseline operating conditions. It is recognized that field measurements are sometimes subject to error or impossible to make; therefore, diagnosis is based on trends rather than individual parameter readings. Even if some basic data are missing, reasonable conclusions may still be drawn.

The techniques described in this report allow the inspector to rapidly identify any significant changes in performance and the possible reasons for the changes. Although these techniques provide a method of assessing compliance, they do not necessarily provide definite evidence of noncompliance, nor do they necessarily recommend specific remedies for problems that are encountered.

Inspectors should have a technical background and some field experience. As with any work involving equipment, care must be exercised and formal safety training is highly recommended for this activity and for any field work involving air pollution control equipment.

No single technique can satisfy all source characteristics and inspection circumstances. Inspectors and source operators may have to modify standard procedures for specific circumstances.

A key inspection step is to determine baseline operating parameters soon after a boiler is installed and the shakedown period has been successfully completed. These baseline parameters, which can be developed during a stack test, will provide a site-specific reference point for assessing future boiler performance. The parameters include:

- Steam production data such as temperature, pressure, and pounds per hour;
- Fuel use - pounds or tons of coal per hour;
- Fuel quality - Btu/lb, ash, sulfur, and moisture;
- Combustion air temperature and ambient humidity;
- Firebox draft;
- Flue gas temperature and flow rate;
- Flue gas O_2, CO, and CO_2;
- Firebox, superheater, and air preheater temperatures;
- Induced-draft fan speed, pressure drop, and air flow;

- Overfire air damper settings; and
- Pollution control system parameters.

The same inspection procedures and forms should be used for both the baseline assessment and the routine evaluation. To round out a reference file, the inspector should:

- Obtain a set of general arrangement drawings of the control equipment and dust or sludge handling system;
- Evaluate the stack test location and procedures to ensure that the emissions data will be accurate and representative; and
- Carefully inspect and describe all internal conditions if such inspections can be conducted safely. Photographs are extremely valuable and should be taken (with permission from the source) if it is safe to do so;
- Note the sounds of operating components such as rappers and solenoids;
- Obtain a complete set of boiler operating conditions, fan characteristics, and raw fuel characteristics; and
- Obtain opacity readings.

Because the inspector is most concerned with emissions, it is generally advisable to begin the inspection by looking at the stack. Then, the inspector should check the control equipment and finish with an inspection of the boiler and the control room. This minimizes inspection time and reporting requirements and maximizes the amount of useful information obtained. Specifically, the information on emissions and control equipment, which is the most relevant to the inspection is obtained early in the inspection and can then be used later either to narrow the scope of the inspection or to terminate the inspection without evaluating the boiler equipment.

- Pre-Inspection Steps

    Review the source files.
    Schedule the inspection.
    Check the inspection equipment.
    Observe the plant surroundings.

- Inspection Procedures

  Request entry to the plant.
  Interview plant official(s).
  Observe the stack effluent.
  Check the continuous monitor(s).
  Measure or record the fan parameters and evaluate the physical condition.
  Analyze the control equipment performance and condition.
  Check the flue gas system (ductwork).
  Evaluate process operating conditions.
  Check raw materials and/or fuels.

- Post-Inspection Steps

  Conduct exit interview with plant official(s).
  Update source files.
  Prepare report.

Prior to entering a plant, the inspector should observe the surrounding areas. Various signs of operating practices and plant emissions that can aid in the source evaluation include:

- Deposits on cars parked near the plant,
- Other signs of dust and fly ash fallout downwind of the plant,
- Fugitive emissions near plant boundaries,
- Conditions around the product and/or waste storage piles, and
- Conditions near lagoons and sludge ponds.

Some of the inspector's observations may suggest that fugitive emission sources should be added to the inspection agenda. A summary of weather conditions also should be included in the inspection report.

Upon arrival at the plant offices, the inspector should notify appropriate plant personnel and show his/her credentials to the plant representative. Generally, the inspector should not sign a visitor release form.

If entry is refused for part or all of a facility within the scope of the inspection, the inspector should carefully note 1) the alleged reason(s) for the refusal of entry, 2) the name and title of the plant official who refused entry, and 3) the time and date that entry was requested. Immediately after such refusal, the inspector should notify his/her supervisor by telephone and provide the above information. Under no circumstances should the field inspector attempt to inform plant personnel of the potential legal consequences of refusal of entry.

Once entry is granted, the inspector should conduct an initial interview with appropriate plant personnel. Some of the points for discussion are:

- The purpose of the inspection,
- The type of measurements to be made,
- The samples (if any) to be acquired,
- The systems to be inspected,
- Changes in plant management that need to be noted in the agency file,

6. Process flowsheets necessary to confirm that reported plant operating conditions are still pertinent, and
7. Operating records required by New Source Performance Standards (NSPS) and/or for determinations of operating conditions specified in permits.

Appropriate regulatory requirements should be reviewed carefully, and their specific applications to the source in question should be discussed with appropriate staff members.

Other issues the inspector should be prepared to discuss include:

- Authority for the inspection;
- Agency organization;
- Scope, timing, and organization of the inspection (preferred inspection agenda); and
- Treatment of confidential data.

The inspector should ask plant officials about the operational status and types and frequencies of malfunctions for all processes and pollution control equipment being inspected. If equipment is not at or near normal conditions, the reasons for deviation should be noted, and the times when units can be expected to be operating at normal conditions should be recorded for use in scheduling followup inspections.

Emission opacities should be observed and recorded according to Method 9 procedures. In many cases, an agency can initiate an enforcement action solely on the basis of visible emission observations. In some cases, however, opacity information can be used to diagnose changes in system performance.

The color of the effluent is another plume characteristic that should be observed. For boilers, the color is an indirect indication of operating conditions. The list in Table 9 was compiled by EPA's Control Programs Development Division.

TABLE 9. PLUME CHARACTERISTICS AND COMBUSTION PARAMETERS.

Plume color	Possible operating parameters to investigate
White	Excess combustion air; loss of burner flame in oil-fired furnace
Gray	Inadequate air supply or distribution
Black	Lack of air; clogged or dirty burners or insufficient atomizing pressure, improper oil preheat; improper coal size
Reddish brown	Excess furnace temperatures or excess air; burner configuration
Bluish white	High sulfur content in fuel

Baseline operating parameters for the boiler and its control equipment may be available from Agency files prior to the inspection. A typical source file contains information on permit activity, previous inspections, and emission tests. The files generally describe the boiler and provide additional data on its capacity and control equipment; this information gives the inspector a perspective on the overall operation of the facility. The source files also may contain information on citizen complaints, equipment malfunctions, opacity levels, and the overall compliance status of the boiler or boilers at the plant. This information helps the inspector to focus attention on those boilers that seem to have problems.

File data on previous emission tests and other inspections should be used to establish a baseline for comparison with information obtained during future inspections or tests. Such information also helps to establish a normal operating range for the boiler and its control equipment and permits the inspector to readily note any deviations.

4.2 SAFETY PRECAUTIONS

Safety precautions must be taken during plant inspections because heavy equipment movement, high-temperature process equipment, high-pressure steam, toxic gases, and noise are common. Extreme caution should be taken to avoid burns and the possibility of slipping and falling. Several specific situations are of concern in terms of the inspector's overall safety.

One special concern is the potential for a boiler explosion. Although an explosion is unlikely, the possibility does exist, especially during nonstandard operating conditions that might be encountered during special tests. The inspector should be familiar with specified evacuation routes and procedures before entering the boiler area.

Because a mixure of pulverized coal and air burns rather freely, suspended coal dust in air can be quite explosive. Hence, pulverized coal or coal dust must not be dispersed in air except within equipment where conditions are controlled at all times. Fine dust can be dispersed into the air by means that are not always expected or predictable; thus, it is important to avoid accumulation of coal dust anywhere in the plant except in coal storage spaces. Even there the suspension of dust in the air must be avoided. In general, it is hazardous to blow dust off surfaces with air lances. Vacuum cleaners designed for this purpose are preferred. Fundamental safety precautions and burner lighting and operating sequences for coal are summarized in the following rules:

1. Never allow coal dust to accumulate except in specified storage facilities.
2. Never allow the suspension of coal or dust in the air except in drying, pulverizing, or burner equipment or in interconnecting ductwork.
3. Purge the furnace and its setting before introducing any light or spark.
4. Have a lighted torch or spark-producing device in operation before introducing fuel into a furnace.

5. Maintain a lighted torch or spark-producing device in operation while introducing fuel into a furnace.

6. Maintain sufficient primary air and coal flows to the burners.

Compliance with these rules requires a conscientious operating staff and good housekeeping throughout the plant.

Another major safety concern at any plant is entry into a confined area. The cardinal rule for entering a confined area is "never trust your senses." What may appear to be a harmless sitation may well be a potential threat. The three most common conditions constituting a threat are:

- Oxygen deficiency,
- Combustible gases and vapors, and
- Toxic gases and vapors.

An inspector should always anticipate that any one or a combination of the above conditions might exist in a confined area such as ductwork, stack, open tanks, penthouse, or the internal portion of a wet scrubber or ESP. Tests for flammability, oxygen deficiency, and toxicity must be made before an inspector enters any confined area. No one factor will provide more safety than the knowledge of the potential threats that may exist within the area to be inspected. Armed with this knowledge, the inspector can take appropriate precautions and use the proper equipment to minimize any potential dangers.

Many treatment chemicals used and handled in the boiler area are corrosive or skin irritants. Care must be taken to avoid contact with these chemical reagents, which may include sodium hydroxide (NaOH), sulfuric acid (H_2SO_4), and chlorine. Table 10 shows the physical, flammable, and toxic properties of common gases that may be encountered in a boiler plant. Many solids may also be hazardous to the skin and eyes; contact should be avoided. The inspector should wear appropriate eye protection (glasses with side shields) at all times within the plant.

Many surfaces in the boiler plant are extremely hot. The inspector should constantly be on the alert for piping, ductwork, or equipment that may present a potential hazard. Protective clothing (long-sleeved shirts, gloves, etc.) should be worn to avoid burns as a result of accidental contact with hot surfaces.

TABLE 10. BOILER PLANT GAS PROPERTIES.

Gas	Physical characteristics	Flammability lower explosive limit (LEL), % volume	Toxicity threshold limit valves (TLV's), % volume
Carbon monoxide (CO)	Colorless Odorless	12.5	0.005
Carbon dioxide (CO_2)	Colorless Odorless	Nonflammable	0.5
Methane (CH_4)	Colorless Odorless	5	Nontoxic
Sulfur dioxide (SO_2)	Colorless Suffocating odor	Nonflammable	0.0005
Nitrogen dioxide (NO_2)	Brown Pungent odor	Nonflammable	0.0005

The inspector should remove loose objects such as jewelry, ties, and hair ribbons before entering the work area. Because of the close quarters in many boiler rooms and the possible contact with moving equipment while taking measurements, any object that might become entangled must be removed.

In addition to the general concerns noted above, an inspector that conducts an internal inspection of any control equipment must:

- Observe interlock and electrical lockout procedures,
- Observe confined entry procedures,
- Watch footing,
- Never work alone,
- Wear protective equipment,
- Purge unit before entry,
- Use grounding straps particularly around ESPs, and
- Never enter full or partially full hoppers (wet- or dry-bottom). Empty hoppers may have ash lodged overhead which also presents a danger if accidently dislodged.

Finally, the inspector needs to be aware of and obey all safety requirements set forth by plant personnel. Many plants have specific safety procedures that must be obeyed; therefore, the inspector must meet with plant personnel prior to the inspection to discuss special safety requirements pertinent to the plant.

4.3 SAFETY AND INSPECTION EQUIPMENT

During an inspection, the inspector should use appropriate protective clothing and safety equipment and follow all company rules and recommendations. The inspector should wear safety glasses with sideshields for protection. Hearing protection, such as ear plugs, should also be used in high-noise-level areas. Steel-toed shoes and a hard hat are required for protection against overhead hazards and heavy objects. A long-sleeved shirt, gloves, and trousers should also be worn for protection. Dust and mist respirators should be used around potentially dusty operations. In some cases a gas mask may be required. When the inspector is required to enter a confined area, he/she may need to use self-contained breathing apparatus.

The equipment used during an inspection varies according to the time allotted and the level of the inspection. For example, a detailed inspection requires a pitot tube and manometer for measuring the pressure drop across the appropriate control equipment, a thermometer or thermocouple for measuring stack gas temperatures, a wet bulb/dry bulb thermometer and psychrometric chart for determining moisture, a tachometer for measuring fan speed, an ammeter for measuring fan motor current (on large fans, current usage may exceed the measurement range of hand-held ammeters), and an oxygen meter and/or Fyrite or Orsat for determining O_2 concentration and gas composition. A flashlight, tape measure, and pressure gauge device may also be necessary.

A camera can be useful to provide a graphical description of problems arising from poor maintenance and housekeeping. Control equipment problems can also be so documented. Immediately after taking a photograph, the inspector should note the situation represented in the picture and the time, date, weather conditions, and pertinent directional information. Unfortunately, the plant owner or operator may be reluctant to allow photographs to be taken within a facility. Therefore, permission must be obtained prior to taking such photographs.

A compass is useful for determining source locations relative to each other, to the sun, and to the inspector. A stopwatch for timing visible emissions observations is also useful.

4.4 PRE-ENTRY OBSERVATIONS

Before entering the facility, the inspector should record pertinent pre-entry observations such as sources of fugitive dust. The inspector should also note the weather conditions (especially precipitation and windspeed) during and prior to the inspection.

Pre-entry observations also afford an opportunity to document the facility's general housekeeping practices and give the inspector an overall picture of the plant layout for comparison with file information.

While outside company property, the inspector is generally free to use a camera to photograph any visible problems, including excessive visible emissions. Data regarding any photographs that may be taken (e.g., date, time of day, weather conditions, position relative to the source) must be recorded immediately. As mentioned in Section 4.3, the inspector must obtain permission from plant personnel to take any photographs while on plant property.

Visible emission observations are important in determining the operating conditions of some processes and their associated control equipment. When recording visual opacity readings, the inspector should follow EPA Method 9 procedures or appropriate State procedures. Windspeed, sky condition, and other weather data should be recorded for future use, as the reading may be challenged in court. A diagram is also important in identifying the particular source being observed (e.g., the No. 3 coal-fired power boiler) and the observer's orientation relative to the sun and the source. The inspector should record opacity readings on the observation form for a specified duration, depending on the local requirements. Any periodicity of smoke emissions, such as intermittent puffs, should be noted. In some cases, it may be possible to correlate variations in opacity with corresponding fluctuations in boiler load or other boiler operating parameters.

Sometimes opacity readings are best obtained before the inspector enters the plant or after he/she leaves the plant property. The inspector should compare the visual measurements with available readings from the plant's continuous emission monitoring equipment for the same time period. The frequency of calibration of these continuous emission monitors should be noted.

If the Agency's policy is to provide the plant with a copy of the opacity readings taken during the inspection, the plant official receiving the copy should sign and date the original record of the opacity readings.

4.5 ONSITE INSPECTION CHECKLISTS

During the onsite inspection, the inspector may find it useful to have a series of checklists on which to record the information obtained. Tables 11 through 13 are checklists for fabric filters, scrubbers, and ESP's respectively. Figures 51, 52, and 53 are flowsheets that can be used in conjunction with the inspection of those control devices.

Appendix A contains additional checklists that may be useful. These checklists include a cover page (Table A-1) that may be used with the checklists for fabric filters (Table A-2), scrubbers (Table A-3), electrostatic precipitators (Table A-4), and mechanical collectors (Table A-5).

TABLE 11. FABRIC FILTERS COUNTERFLOW INSPECTION DIAGNOSTIC SECTION.

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
A. Bag Tears or Pinholes						
1. Filter house pressure drop low (<80% avg.)			E		3	If sum (Σ) of ratings is ≥ 10, perform internal inspection. Check for deposits on filter house clean side. Check inaccessible bags. Use fluorescent dye technique. Check integrity of fabric by attempting to extend rips.
2. Opacity high			E		5	
3. Bag age high (typical avg.)			E		5	
4. Some bags inaccessible	N/A	N/A	I		2	
5. Design A/C high (>120% avg.)			E		4	
6. Actual A/C high (>120% avg.)			E		4	
7. Wear plate eroded	N/A	N/A	I		3	
8. Frequent high excursions			E or I		4	
				Σ =		
B. Bag Blinding						
1. Filter house pressure drop high (>150% avg.)			E		7	If sum (Σ) of ratings is >10, perform internal inspection. Check dirty side of bags for coatings (this may be difficult to identify in some cases). Check records for steady rise in filter house pressure drop. Reschedule inspection in near future.
2. Opacity low			E		2	
3. Cleaning frequency high (cycles/day)			E		5	
4. Gas temp low (≤20°F avg.)			E		4	
5. Moisture in gas stream	N/A	N/A	E		4	
6. Particulate sticky	N/A	N/A	E		4	
7. Air in-leakage (hoppers/ access doors)	N/A	N/A	I		2	
8. Unit not insulated	N/A	N/A	E		2	
				Σ =		
C. Bag Bleeding						
1. Opacity high			E		5	If sum (Σ) of ratings is >10, attempt to confirm uses of fluorescent dye and black light.
2. Pressure drop gradually increasing			E		2	
3. Cleaning frequency high			E		5	
				Σ =		

(Continued)

*Location: E is external, and I is internal.

TABLE 11. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
D. Cleaning System						
1. Filter house pressure drop high			E		5	If sum (Σ) of ratings is ≥ 10, perform internal inspection and check deposits on dirty side of bags. Check bag tension. Reschedule inspection in near future.
2. Pulse-jet air header pressure low			E		5	
3. Solenoids inoperative	N/A	N/A	E or I		10	
4. Reverse air fan inoperative	N/A	N/A	E or I		10	
5. Shaker motor inoperative	N/A	N/A	E or I		10	
6. Bag length long			E		2	
7. Equipment inaccessible	N/A	N/A	I		2	
8. High intensity cleaning required			E		2	
				Σ =		
E. Hopper						
1. Filter house pressure drop high			E		5	If sum (Σ) of ratings is ≥ 10, perform internal inspection of hoppers.
2. Solids-removal run intermittent	N/A	N/A	E		3	
3. Indicator level existent and/or inoperative	N/A	N/A	E		2	
4. Heaters nonexistent and/or inoperative	N/A	N/A	E		2	
5. Vibrators nonexistent and/or inoperative	N/A	N/A	E		2	
6. Hopper valves corroded	N/A	N/A	I		3	
7. Hopper slope <60°	N/A	N/A	E		2	
8. Hoppers not insulated	N/A	N/A	E		2	
9. Winter	N/A	N/A	E		2	
10. Hammer markings on hopper walls	N/A	N/A	E		2	
11. Conveyor inoperative	N/A	N/A	E		10	
				Σ =		

*Location: E is external, and I is internal.

TABLE 12. SCRUBBERS COUNTERFLOW INSPECTION DIAGNOSTIC SECTION.

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
A. No Liquor Flow						
1. Pumps are inoperative	N/A	Yes, No	E		10	If sum (Σ) of ratings ≥10, request immediate correction action, and/or stack test.
2. Inlet and outlet gas temps same	N/A	N/A	E		10	
3. Opacity high			E		5	
4. Scrubber pressure drop low			E		5	
5. Nozzles plugged	N/A	Yes, No	I		7	
					Σ =	
B. Low Liquor Flow						
1. Nozzle operating pressure (<80% avg.)			E		3	If sum (Σ) of ratings is ≥10, attempt to measure exit water flow rate to confirm conclusions. Request stack test.
2. Gas temp high (10% above avg.)			E		3	
3. Opacity high			E		5	
4. Recirculation liquor pH low (<5)			E		3	
5. Flow rate monitor value low (<80% avg.)			E		7	
6. Scrubber pressure drop low (<80% avg.)			E		3	
7. Exit water temp high (>20% above avg.)			E		3	
					Σ =	
C. Gas Flow Rate High						
1. Opacity high			E		5	If sum (Σ) of ratings is ≥ 10, check process equipment and production rate.
2. Outlet gas stream temp high (>20°F above avg.)			E		5	
3. Exit water temp high (>20°F above avg.)			E		5	
					Σ =	

*Location: E is external, and I is internal.

(Continued)

TABLE 12. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
D. Gas Flow Rate High						
1. Opacity high			E		5	If sum (Σ) of ratings is ≥10, check process equipment and production rate. Request stack test if problem is serious.
2. Temp of outlet gas low (>20°F below avg.)			E		3	
3. Temp of exit liquor low (>20°F below avg.)			E		5	
4. Scrubber pressure drop low (<80% avg.)			E		5	
				Σ =		
E. Bed Plugging						
1. Scrubber pressure drop high (>40% above avg.)			E		5	If sum (Σ) of ratings is ≥10, check for bypassing of effluent around scrubber. Request immediate corrective action.
2. Liquor turbidity high	N/A	N/A	E		5	
3. Liquor pH high (>8)			E		5	
				Σ =		
F. Nozzle Erosion						
1. Nozzle operating pressure drop low (<80% avg.)			E		5	If sum (Σ) of ratings is ≥10, recommend nozzle replacement.
2. Opacity high			E		3	
3. Liquor turbidity high	N/A	N/A	E		3	
4. Corrosive liquor	N/A	N/A	E		3	
5. Nozzles unchanged in 6 months	N/A	N/A	E		3	
6. Nozzles operable	N/A	N/A	I		10	
				Σ =		

*Location: E is external, and I is internal.

(Continued)

TABLE 12. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
G. Demister						
1. No water flow to demister	____	____	I	____	5	If sum (Σ) of ratings is ≥10, check for changes in productio rate. Reschedule inspection in near future in anticipation of fan unbalance problem.
2. Gas velocity high (>10 ft. per second)	____	____	E	____	10	
3. Fan vibrating	____	____	E	____	5	
					Σ = ____	
H. Venturi Throat Adjustment						
1. Scrubber pressure drop low (<80% avg.)	____	____	E	____	4	If sum (Σ) of ratings is ≥10, request corrective action immediately or request stack test.
2. Visible evidence of changes	N/A	N/A	E	____	4	
3. Opacity high	____	____	E	____	4	
					Σ = ____	
I. Impingement Plate or Tray Collapse						
1. Pressure drop low (<80% avg.)	____	____	E	____	4	If sum (Σ) of ratings is ≥10, attempt internal inspection.
2. Opacity high	____	____	E	____	4	
3. Build-up of liquor in sump	N/A	N/A	I	____	4	
					Σ = ____	
J. In-leakage of Air						
1. Temp of gas stream low	____	____	E	____	5	If sum (Σ) of ratings is ≥10, attempt internal inspection.
2. Obvious shell corrosion	N/A	N/A	I	____	5	
					Σ = ____	

*Location: E is external, and I is internal.

TABLE 13. ELECTROSTATIC PRECIPITATORS COUNTERFLOW INSPECTION DIAGNOSTIC SECTION.

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
I. ELECTRICAL						
A. Particle Resistivity						
1. Peak voltage low (down 5-10 kv)			E		5	If sum (Σ) of ratings is ≥10, request in-situ resistivity tes and check sulfur content of fuel, moisture content of gas, and temperature of gas.
2. Rapping intensity increased			E		5	
3. Temp changed (±50°F)			E		3	
4. Spark rate increased (±50 sparks/min)			E		5	
5. Opacity high			E		6	
6. Coal sulfur content low (<1.0%)			E		6	
				Σ =		
B. Transformer-Rectifier Set Problems						
1. No secondary current	N/A	N/A	E		10	If sum (Σ) of ratings is ≥10, request repair.
2. No penthouse purge	N/A	N/A	E		2	
3. Voltage zero, current high	N/A	N/A	E		10	
4. Opacity high			E		6	
				Σ =		
C. Insulator Failure						
1. Peak voltage low			E		5	If sum (Σ) of ratings is ≥10, request repair.
2. Penthouse purge (not used)	N/A	N/A	E		5	
3. Penthouse temp high (+20°F)			E		3	
4. Opacity high			E		6	
5. Cracks visible	N/A	N/A	I		10	
				Σ =		

(Continued)

*Location: E is external, and I is internal.

TABLE 13. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
D. Broken Discharge Wires						
1. Deposits on wires	N/A	N/A	I	____	5	If sum (Σ) of ratings is ≥10, request repair.
2. Violent meter fluctuating	N/A	N/A	E	____	10	
3. Hopper level indicator not used	N/A	N/A	E	____	2	
4. Spark rate high (±50 sparks/min)	____	____	E	____	5	
5. Opacity high	____	____	E	____	3	
6. Broken discharge wires	N/A	N/A	I	____	10	
				Σ =	____	
II. GAS FLOW						
A. Excessive Velocity						
1. Flow rate high	____	____	E	____	5	If sum (Σ) of ratings is ≥10, check production and/or generator rate.
2. Voltages high, currents low	____	____	E	____	5	
3. Opacity high	____	____	E	____	5	
				Σ =	____	
B. Nonuniform Distribution						
1. Flow rate increased	____	____	E	____	2	If sum (Σ) of ratings is ≥10, request velocity traverse.
2. Secondary currents nonparallel	N/A	N/A	E	____	5	
3. Hopper levels differences on parallel branches	____	____	I	____	5	
4. Rappers on distribution plates not used	N/A	N/A	E or I	____	3	
				Σ =	____	

*Location: E is external, and I is internal.

(Continued)

TABLE 13. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
III. MECHANICAL						
A. Rapper Problems						
1. Puffs visible	N/A	N/A	E		5	If sum (Σ) of ratings is >10, request internal inspection by plant personnel. Request intensity measurement, if appropriat
2. Peak voltage changed, secondary current constant			E		5	
3. Spark rate changed			E		3	
4. Low sulfur coal used			E		3	
5. Dust sticky	N/A	N/A	E		3	
					Σ =	
B. Hopper Solids Removals						
1. Broken discharge wires	N/A	N/A	I		5	If sum (Σ) of ratings is >10, request internal inspection and/or changes in operational practices.
2. Mass loading probably increased	N/A	N/A	E		5	
3. Nonuniform gas distribution	N/A	N/A	E		3	
4. Hoppers not emptied continuously	N/A	N/A	E		5	
5. Level indicators not used	N/A	N/A	E		3	
6. Heaters not used	N/A	N/A	E		2	
7. Vibrators not used	N/A	N/A	E		2	
8. Hoppers not insulated	N/A	N/A	E		2	
9. Corrosion around outlet valves	N/A	N/A	I		3	
10. Hopper slope <60°	N/A	N/A	E		3	
11. Hoppers full or bridged	N/A	N/A	I		10	
					Σ =	

*Location: E is external, and I is internal.

(Continued)

TABLE 13. (continued)

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
III. MECHANICAL (continued)						
C. Collection Plate Warp and Malalignment						
1. Change in air load	N/A	N/A	E		5	If sum (Σ) of ratings is ≥10, request alignment check.
2. Repeated hopper overflow	N/A	N/A	E or I		3	
3. Air in-leakage	N/A	N/A	E		3	
4. Malalignment visible	N/A	N/A	I		10	
				Σ =		
IV. EFFLUENT CHARACTERISTICS						
A. Mass Loading Increases						
1. Opacity high			E		6	If sum (Σ) of ratings is ≥10, check production and/or generator rate.
2. Inlet section, secondary currents low			I		5	
3. Hopper unloading frequency increases			E		2	
				Σ =		

*Location: E is external, and I is internal.

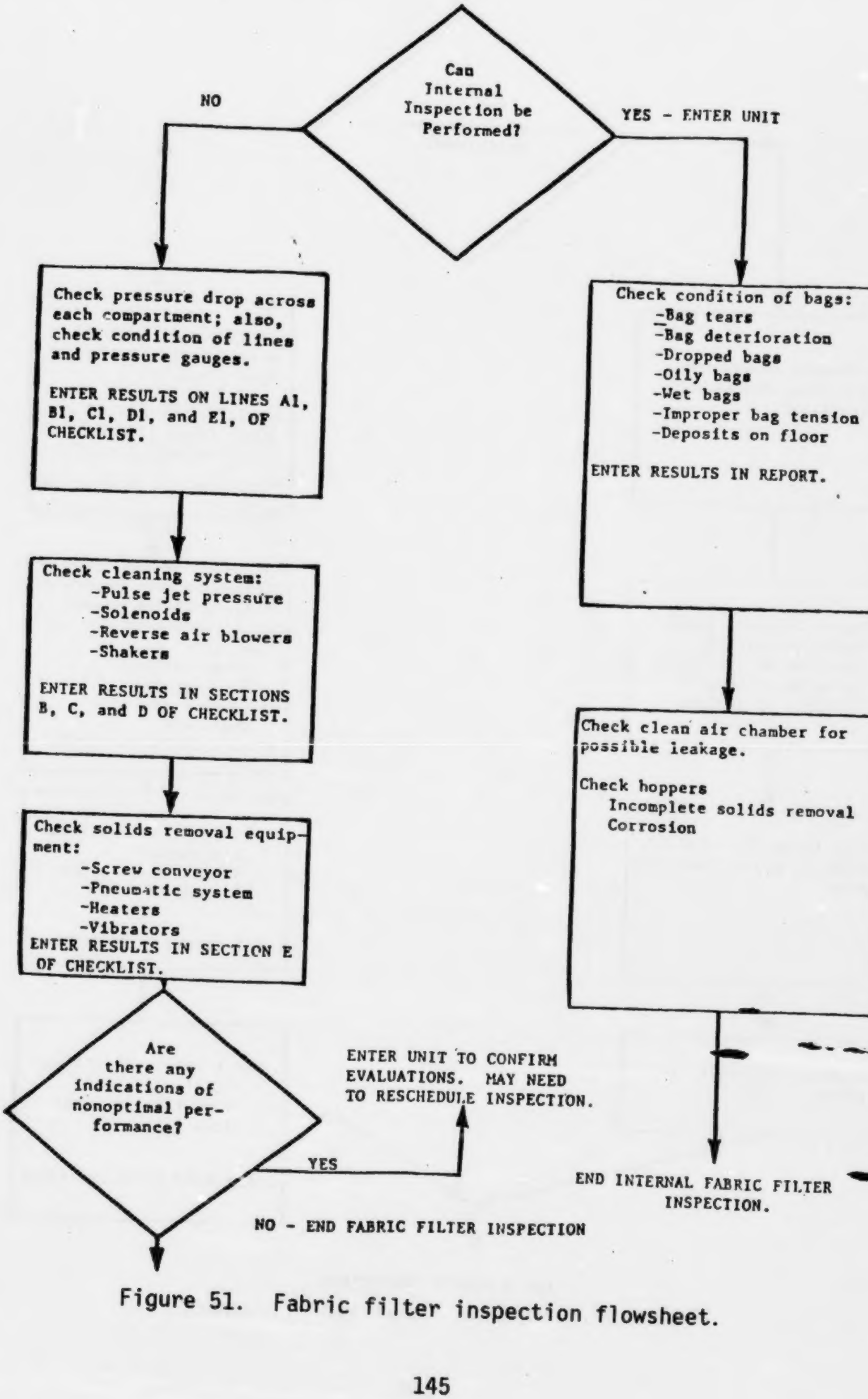

Can Internal Inspection be Performed?
NO
YES - ENTER UNIT
Check pressure drop across each compartment; also, check condition of lines and pressure gauges.
ENTER RESULTS ON LINES A1, B1, C1, D1, and E1, OF CHECKLIST.
Check cleaning system:
-Pulse jet pressure
-Solenoids
-Reverse air blowers
-Shakers
ENTER RESULTS IN SECTIONS B, C, and D OF CHECKLIST.
Check solids removal equipment:
-Screw conveyor
-Pneumatic system
-Heaters
-Vibrators
ENTER RESULTS IN SECTION E OF CHECKLIST.
Are there any indications of nonoptimal performance?
YES
ENTER UNIT TO CONFIRM EVALUATIONS. MAY NEED TO RESCHEDULE INSPECTION.
NO - END FABRIC FILTER INSPECTION
Check condition of bags:
-Bag tears
-Bag deterioration
-Dropped bags
-Oily bags
-Wet bags
-Improper bag tension
-Deposits on floor
ENTER RESULTS IN REPORT.
Check clean air chamber for possible leakage.
Check hoppers
Incomplete solids removal
Corrosion
END INTERNAL FABRIC FILTER INSPECTION.

Figure 51. Fabric filter inspection flowsheet.

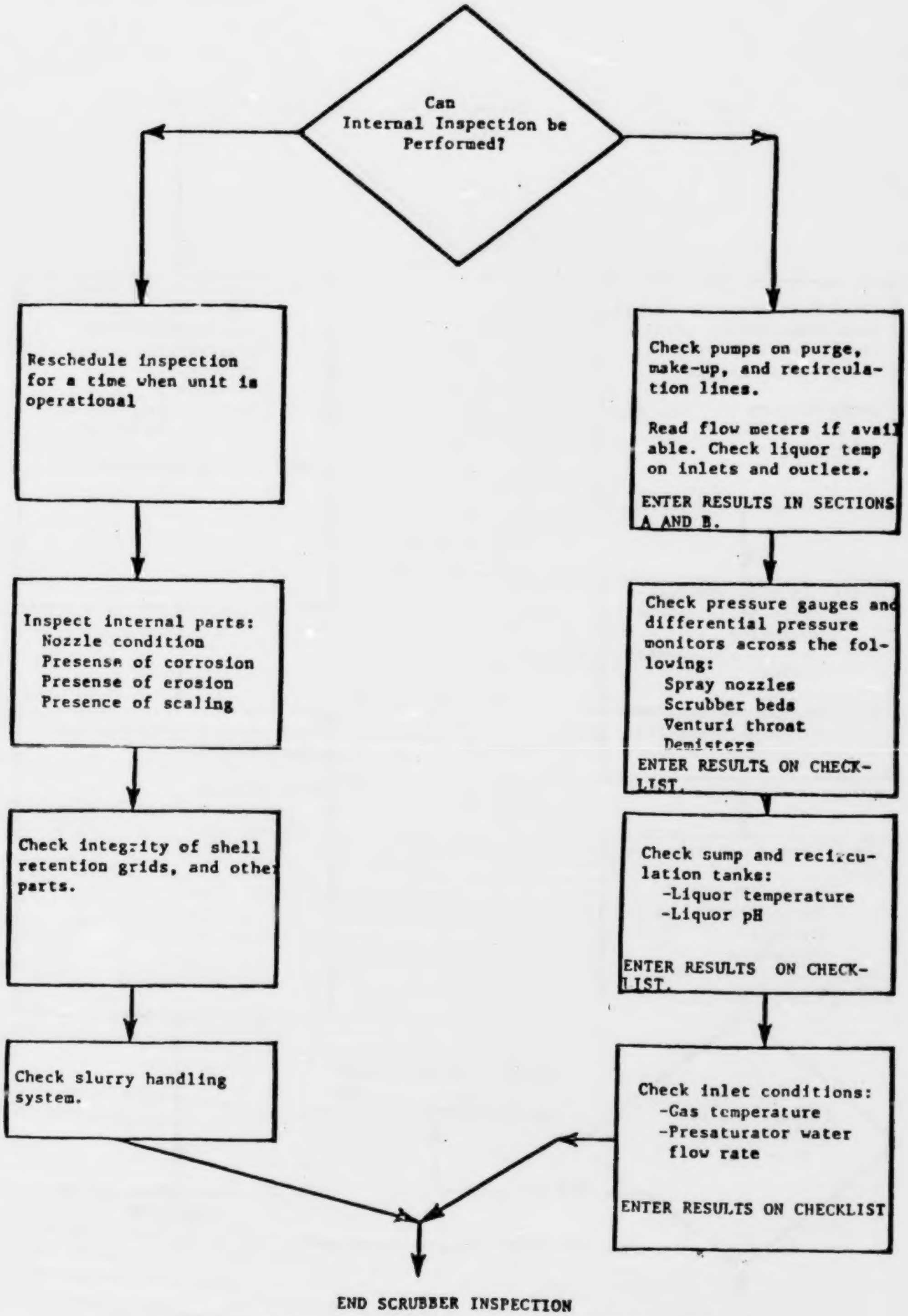

Can Internal Inspection be Performed?
Reschedule inspection for a time when unit is operational
Inspect internal parts:
Nozzle condition
Presense of corrosion
Presense of erosion
Presence of scaling
Check integrity of shell retention grids, and othe parts.
Check slurry handling system.
Check pumps on purge, make-up, and recirculation lines.
Read flow meters if avai able. Check liquor temp on inlets and outlets.
ENTER RESULTS IN SECTIONS A AND B.
Check pressure gauges an differential pressure monitors across the following:
Spray nozzles
Scrubber beds
Venturi throat
Demisters
ENTER RESULTS ON CHECKLIST.
Check sump and recirculation tanks:
-Liquor temperature
-Liquor pH
ENTER RESULTS ON CHECKLIST.
Check inlet conditions:
-Gas temperature
-Presaturator water flow rate
ENTER RESULTS ON CHECKLIST
END SCRUBBER INSPECTION

Figure 52. Scrubber inspection flowsheet.

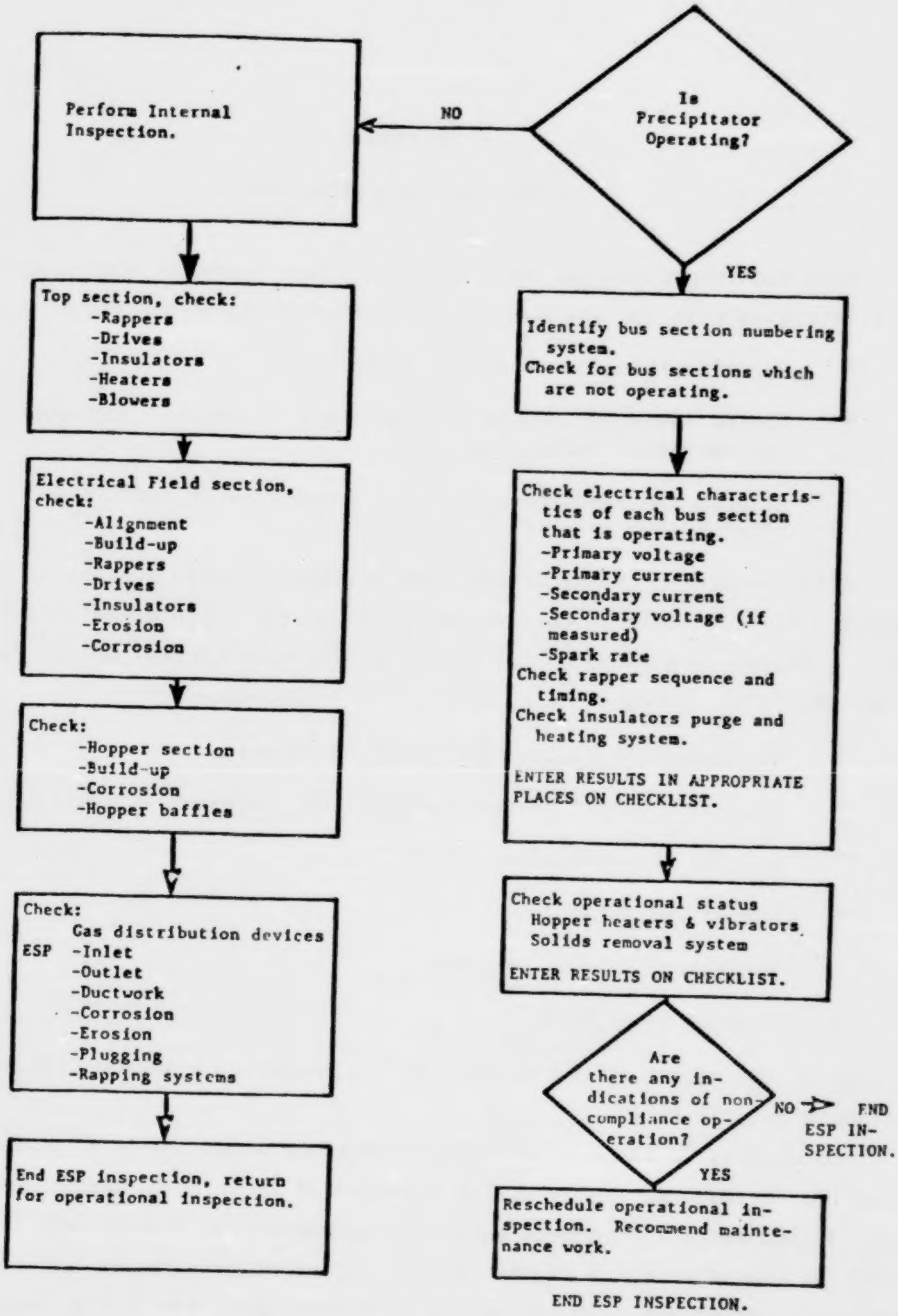

Perform Internal Inspection.
NO
Is Precipitator Operating?
YES
Top section, check:
-Rappers
-Drives
-Insulators
-Heaters
-Blowers
Identify bus section numbering system.
Check for bus sections which are not operating.
Electrical Field section, check:
-Alignment
-Build-up
-Rappers
-Drives
-Insulators
-Erosion
-Corrosion
Check electrical characteristics of each bus section that is operating.
-Primary voltage
-Primary current
-Secondary current
-Secondary voltage (if measured)
-Spark rate
Check rapper sequence and timing.
Check insulators purge and heating system.
ENTER RESULTS IN APPROPRIATE PLACES ON CHECKLIST.
Check:
-Hopper section
-Build-up
-Corrosion
-Hopper baffles
Check operational status
Hopper heaters & vibrators
Solids removal system
ENTER RESULTS ON CHECKLIST.
Check:
Gas distribution devices
ESP -Inlet
-Outlet
-Ductwork
-Corrosion
-Erosion
-Plugging
-Rapping systems
Are there any indications of noncompliance operation?
NO
END ESP INSPECTION.
YES
End ESP inspection, return for operational inspection.
Reschedule operational inspection. Recommend maintenance work.
END ESP INSPECTION.

Figure 53. Electrostatic precipitator inspection flowsheet.

SECTION 5

COMPLIANCE DETERMINATION

When the inspection has been completed, the inspector should conduct an exit interview with the source. During that meeting he/she should:

- Ask clarifying questions as necessary,
- Review inspection notes so that there is general agreement on the technical facts, and
- Discuss the need for a followup inspection or additional records.

After returning to the office, the inspector should prepare an inspection report. All conclusions based on observations and calculations should be clearly stated, and a diagnostic checklist for each control device in the plant should be included. The report should also document:

- Any change in responsible plant personnel,
- Requested permit changes or reported process modifications,
- Results of evaluation,
- Action requested,
- Inspector's signature, and
- Date of inspection.

A copy of the report should be kept in the inspector's source file and in the Agency's central file.

Comprehensive inspections require that the inspector have an established baseline for each parameter during a period of known compliance. The baseline should document all pertinent operating parameters as they relate to the emission characteristics of the source, including all process and control equipment parameters. In collecting pertinent data, the Agency should be certain (1) the data are needed, (2) that a change in the value of a parameter has an effect on the operation of the source, and (3) that the data are accurate. Checklists (as presented in Section 4) are especially useful. The baseline establishes a fixed point of operation and the appropriate values of operating parameters against which other determinations can be made. The emission test at that point of operation documents the emissions that may be correlated with process and control equipment operating characteristics derived during the test. The baseline test results are useful in subsequent routine inspections. When an operation and maintenance program or permit to operate is issued based on a range of process and control equipment parameters, the Agency must be able to measure these parameters. For this reason, maintenance and calibration of the key parameter instrumentation are required prior to the performance test. Additional instrumentation also may be needed in some cases.

The baseline must be used for documenting deviations from normal conditions for each process or control device operating parameter. A substantial change in the parameter is evaluated based on its impact on overall emission levels. For example, an increase in boiler firing rate would be evaluated because of its impact on the uncontrolled emission rate from the boiler.

The efficiency of the ESP serving a coal-fired boiler can be estimated by using variables that define the power input to the system and the gas flow being treated. The equation that is generally applied is a modified version of the Deutsch-Anderson equation. This equation contains a parameter that must be estimated or calculated from a previous baseline performance test. To apply this method, the inspector must be able to determine the flue gas flow rate through the ESP and the power input to the ESP. He/she must also be able to determine that the unit is in reasonably good operating condition (no gross gas maldistribution, power distribution imbalances, high resuspension rates, or high rapper reentrainment) because poor conditions can severely impair the performance of the ESP.

The performance of an ESP should be evaluated in relation to previous baseline tests and observations. In rare cases, it is possible that stack tests have been conducted over a range of boiler loads and at several ESP power input levels. In such cases, an inspector may be able to estimate emissions if operating parameters are within the range of operating conditions that have been tested. Table 14 lists the effects of several operating parameters of boilers, ESPs, and fabric filters on particulate emissions.

TABLE 14. SUMMARY OF THE EFFECTS OF SEVERAL OPERATING PARAMETERS OF BOILERS, ESPS, AND FABRIC FILTERS ON PARTICULATE EMISSION RATES.

Parameter	Change	Effect on particulate emission rate
Firing rate	Increase	Increase
Primary air	Increase	Increase
Excess air	Increase	Increase
ESP power input	Decrease	Increase
ESP superficial velocity	Decrease	Decrease
Fabric filter air-to-cloth ratio	Increase	Increase
Fabric filter pressure drop	Increase	Increase
Flue gas oxygen[a]	Increase	Increase
Primary air temperature	Decrease	Decrease
Visible emissions	Increase	Increase

[a] If increase in oxygen is a result of an increase in primary air volume.

The inspection provides information on the key operating parameters of the boiler and pollution control equipment. Based on increases or decreases in specific parameters, the inspector can determine whether emissions have increased or decreased. Without a stack test, the inspector cannot determine compliance with the standards. Similarly, without visible emissions measurements, he/she cannot determine compliance with the visible emissions standard. Based on the data collected during an inspection, however, the inspector can subjectively determine compliance.

The data should be arranged in an orderly fashion (as shown in the checklist order), and for each recorded parameter the baseline data and the latest inspection data should be tabulated for comparison. Beside each tabulated value the inspector should note the impact of the parameter on the source emissions (i.e., no change, an increase, or a decrease). This process provides a useful table of increases and decreases in emissions for the inspector's subjective evaluation.

A few specific equations can be applied to the data to provide additional information on emissions. The inspector should be familiar with the Deutsch-Anderson equation for electrostatic precipators for use in estimating ESP emissions.[8] Plots of ESP voltage-current data can be effective for diagnosing malfunctions that can cause an increase in emissions.[9] Several manufacturers of particulate scrubbers also use empirical equations to calculate emissions, and the inspector should be familiar with these equations as well. Sources equipped with fabric filters must be evaluated subjectively because no suitable equations are available for estimating emissions from fabric filters based on data that would be collected during an inspection.

During an inspection the following differences in operation from the baseline conditions were noted:

	Baseline	Inspection	Effect on emissions
Fuel consumption	250 lb/h	210 lb/h	Decrease
Air flow	63,000 acfm	53,000 acfm	Decrease
Steam production	2050 lb/h	1700 lb/h	Decrease
Fan motor current	30 amps	26 amps	Decrease
Fabric filter[a] pressure drop	3 in. H_2O	2 in. H_2O	Decrease
Opacity	5%	10%	Increase
Fan static pressure	9 in. H_2O	6 in. H_2O	Increase

[a] Overall

Based on the information in Table 14, it is possible that the unit would not be in compliance with the particulate emission standard if the boiler were operating at baseline conditions. The increase in opacity of emissions from the fabric filter indicates that the filter has missing bags, torn bags, or other bag problems.

The relationship between pressure drop and the air flow through a fabric filter is nearly linear. Based on the fuel consumption, heat content, stack oxygen, and F factor, the air volume changed from 63,000 acfm to 53,000 acfm. With a 3 in. H_2O pressure at baseline conditions the pressure drop at the time of the inspection should be 2.5 in. H_2O or slightly higher than the observed value.

The fan data indicate a drop in current usage due to the decreased air flow and the drop in static pressure. Since the pressure drop across the fan is only 2 in. H_2O instead of the 2.5 in. H_2O expected using the F-factor, it can be assumed that a bag is torn or missing. This confirms the higher opacity exhibited by the fabric filter.

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APPENDIX A

POLLUTION CONTROL DEVICE DIAGNOSTIC CHECKLISTS AND DATA SHEETS

TABLE A-1. CONTROL DEVICE DIAGNOSTIC CHECKLIST AND COVER PAGE

INSPECTION REPORT

REPORT NUMBER ____________________

PLANT NAME ____________________

PLANT I.D. ____________________

SPECIAL ACTION RECOMMENDED (Yes) (No)

I. GENERAL INFORMATION

A. Sources Inspected ____________ Production Status ____________

____________ ____________

____________ ____________

____________ ____________

B. Reasons for Inspection (Check Appropriate Items)

Routine Inspection ____________ Compliance Progress ____________
Complaint Investigation ____________ Permit Review/Renewal ____________
Stack Testing Observed ____________ Tax Certification ____________
Special Studies ____________ Emergency Episode ____________
Other ____________ Equipment Malfunction ____________

C. Plant Representative Contacted (Name and Title) ____________

____

D. Inspection Procedures and Conditions

Prior Notice (Check One) Yes ____ No ____

Time/Date ____________ Duration On-Site ____________ ____________

Type Inspection (Check One) Counterflow ________ Follow-Up ________

Other ____________

Weather ____________ Wind Direction ____________

II. PRE-INSPECTION INTERVIEW

A. Production Status: Normal ____________ Abnormal ____________
B. Control Equipment: Normal ____________ Abnormal ____________
C. Permit/Compliance Schedule Changes Needed: Yes ________ No ________
D. Comments ____________________

____

____

(continued)

TABLE A-1 (continued)

Report Number ____________________

III. INSPECTION RESULTS

A. General Conclusions

All Sources in Compliance with:

Mass Emission Regulations: Yes ______ No ______ N/A ______
Visible Emission Regulations: Yes ______ No ______ N/A ______
Fuel Quality Regulations: Yes ______ No ______ N/A ______
Continuous Monitoring Regulations: Yes ______ No ______ N/A ______
Sampling/Testing Requirements: Yes ______ No ______ N/A ______
Recordkeeping Requirements: Yes ______ No ______ N/A ______
Permit Stipulations: Yes ______ No ______ N/A ______
Special Orders: Yes ______ No ______ N/A ______

O&M Practices: Good ________ Average ________ Poor ________
Housekeeping: Good ________ Average ________ Poor ________

B. Specific Conclusions

Compliance Questionable Due To:

Changes in Raw Materials and/or Fuels ____________________
Production Rates Increases ____________________
Operational Changes in Process ____________________
Deterioration of Process Equipment ____________________

Operational Problems in Control Equipment (Check Appropriate Items Below)

Electrostatic Precipitators

Resistivity ________
TR Sets ________
Insulators ________
Discharge Wires ________
High Velocity ________
Gas Distribution ________
Rappers ________
Solids Handling ________
Plate Warpage ________
Mass Overload ________
Other ________

Fabric Filters

Tears/Pinholes ____
Blinding ________
Bleeding ________
Cleaning System ____
Hopper Overflow ____
Corrosion ________

Wet Scrubbers

Low Liquor Flow ________
Gas Flow Rate Low ______
Bed Plugging ________
Nozzle Erosion ________
Demisters ________
Throat Adjustment ______
Tray Collapse ________
Corrosion ________

C. Samples Taken (Describe) ____________________

____

____

D. Comments/Recommended Action ____________________

____

____

Inspector ______________ Date ________

Reviewer ______________ Date ________

TABLE A-2. FABRIC FILTER INSPECTION DATA SHEET

A. INSPECTION INFORMATION

1. IDENTIFICATION

Company______________________________________

Plant Name___________________________________

Plant I.D. Number______________________________

Address______________________________________

____

____

Control Device/System Number____________________

Process Served_________________________________

2. PROCEDURES AND CONDITIONS

Prior Notice: Yes_____ No_____

Time(s) On-Site________________________________

____

Type Inspection________________________________

____

Inspectors____________________________________

____

____

Plant Representatives___________________________

____

____

Information Claimed Confidential: Yes_____ No_____

TABLE A-2 (continued)

B. Visible Emissions Observations

Inspection No. ______
Equipment No. ______
Confidential: Yes ___ No ___
Page No. _____ of _____

1. STACK CHARACTERISTICS

Location ______
Height ______
Temperature ______
Exit Dimensions ______
Orientation ______
Other Information ______

2. STACK EFFLUENT

Detached Plume: No _____ Yes _____ Distance ______
Color ______
Puffing: Yes ______ No ______
Opacity

Time	Average Opacity	Observation Point	Sheet No.

3. FUGITIVE EMISSIONS

Control Device: Yes _____ No _____
Solids Removal System: Yes _____ No _____
Process: Yes _____ No _____
Continuous ______ Intermittent ______
Adjacent Deposits: Yes _____ No _____

TABLE A-2 (continued)

C. Fan Data

Inspection No.__________
Equipment No.__________
Confidential: Yes ___ No ___
Page No. ____ of ____

1. FAN MOTOR

Manufacturer____________________
Model No.__________ Type__________
Rated Horsepower ____________________
Volts__________ Maximum Amps__________
Maximum R.P.M. __________ Service factor __________
Operating Current: Panel__________ Other__________

2. DRIVE

Direct__________Belt__________Other __________
Sheath Reduction____________________
Audible Belt Slippage: Yes__________ No __________

3. FAN

Manufacturer ____________________
Model No.__________ Type__________
Fan Vibration____________________
Gas Temperature at inlet, °F____________________
Fan R.P.M.____________________
____
Fan Static Pressures: Inlet__________ Outlet__________
Differential Static Pressures: Measured______ Panel ______
Fan Housing Condition____________________
Dampers____________________
Fan Exit____________________

TABLE A-2 (continued)

D. Fabric Filter Data

Inspection No. ____________
Equipment No. ____________
Confidential: Yes ____ No ___
Page No. _______ of _______

1. DESCRIPTIVE INFORMATION

Fabric Filter Type ______________________________
Manufacturer ______________________________
Model No. ______________________________
Plant Inventory No. ______________________________
Date Installed ______________________________

2. LOCATION

Building/Area ______________________________
Inside ______________________ Outside ______________

3. LAYOUT (SKETCH FABRIC FILTER, FAN, INLET, SOLIDS REMOVAL, ETC.).

TABLE A-2 (continued)

E. Fabric Filter External Inspection

Inspection No. ____________
Equipment No. ____________
Confidential: Yes ____ No ____
Page No. ______ of ______

1. SOLIDS REMOVAL

Valve Type: Rotary ________ Flapper ________ Other ________
Valve Speed/Frequency ____________
Transport Equipment: Screws ________ Other ________
Transport Equipment Operating: Yes ________ No ________
Transport Equipment Discharging Solids: Yes ________ No ________
Characterize Discharge ____________
____
____

Hopper Vibrators: Yes ________ No ________
Hopper Insulation: Yes ________ No ________
Hopper Level Indicators ____________
____

Hopper Condition ____________
____
____

Disposal Method ____________
____
____

2. SHELL CONDITIONS

Insulated: Yes ________ No ________
Possible Weld/Seam Gaps, Characterize ____________
____
____
____
____

TABLE A-2 (continued)

E. Fabric Filter External Inspection

Inspection No. ______________
Equipment No. ______________
Confidential: Yes ___ No ___
Page No. ______ of ______

3. OPERATING CONDITIONS

Static Pressure on Clean Side, ______________ in. H_2O
Static Pressure on Dirty Side, ______________ in. H_2O
On-site Monitor, Differential Static Pressure ______________ in. H_2O
Tap Conditions ______________
Gas Inlet Temperature ______________ °F

4. CLEANING SYSTEMS

Type ______________
Frequency ______________
____
____
Air Pressure, ______________ PSIG
Drier: Yes ______________ No ______________
Evidence of Water and/or Oil Problems ______________
____
____
Solenoids Inoperative ______________

5. PRECLEANERS

Type ______________
Static Pressures: Inlet ______________ Outlet ______________ in. H_2O
Gas Inlet Temperature ______________ °F

TABLE A-2 (continued)

F. Fabric Filter Internal Inspection

Inspection No. ____________

Equipment No. ____________

Confidential: Yes ___ No ___

Page No. _______ of _______

1. PURPOSE

Reason(s) Necessary

Inventory Check ____________

Comprehensive Inspection ____________

Other ____________

Safety Evaluation (Describe if applicable)

Respirator Necessary ____________

Temperature ____________ °F

O_2 ____________ %

Combustibles ____________ %

Electrical Grounding ____________

Mechanical Hazards ____________

Noise ____________

Other ____________

Inspection Conducted: Yes ____________ No ____________

Inspection Not Performed Due to Safety ____________

2. BAG LAYOUT (ATTACH DRAWING)

No. of bags ____________

Length ____________ ft

Diameter ____________ in.

Material (Characterize) ____________

____

Attachment(s) ____________

____

____

TABLE A-2 (continued)

F. Fabric Filter Internal Inspection

Inspection No. ______________

Equipment No. ______________

Confidential: Yes ____ No ___

Page No. _______ of _______

3. HATCH CONDITIONS

Gaskets ____

____

Corrosion ____

____

Bolts/Ears ____

____

Ease of Access ____

____

4. LEAK JETS

Location ____

____

____

Number ____

5. BAG CONDITIONS

____

____

____

____

____

____

____

Table A-2 (continued)

F. Fabric Filter Internal Inspection

Inspection No. ______________

Equipment No. ______________

Confidential: Yes ____ No ___

Page No. _______ of _______

6. HOPPERS AND BLAST PLATES

____

____

____

____

____

7. CLEANING APPARATUS

____

____

____

____

____

TABLE A-2 (continued)

G Samples

Inspection No. ______________
Equipment No. ______________
Confidential: Yes ____ No ____
Page No. _______ **of** _______

1. SOLIDS DEPOSITS

Sample No. ______________________________
Location Obtained ______________________________
Date/Time Obtained ______________________________
Results ______________________________
____
____
____
____

2. FABRIC SAMPLES

Sample No. ______________________________
Location Obtained ______________________________
Date/Time Obtained ______________________________
Permeability ______________________________
Tensile Strength ______________________________
Count ______________________________
Weight/Yard^2 ______________________________

3. OTHER

____
____
____
____
____
____
____

TABLE A-2 (continued)

H Ventilation System

Inspection No. ____________

Equipment No. ____________

Confidential: Yes ___ No ___

Page No. ______ of ______

1. DUCTS (SHOW STATIC PRESSURES ON LAYOUT.)

2. HOOD

Configuration

Average Capture Velocity ______________________________ ft/min

Thermal Drafts (Characterize) ______________________________

____

____

Cross Currents (Characterize) ______________________________

____

____

Estimated Effectiveness ______________________________

TABLE A-2 (continued)

Process

Inspection No. ____________
Equipment No. ____________
Confidential: Yes ____ No ___
Page No. ______ of _____

1. PROCESS TYPE

Characterize Source ____________________________________
____
____
____

Operating Schedule ____________________________________
____
____
____

2. OPERATION

Product Type During Inspection ____________________________
____
____

Production Rate During Inspection __________________________
____
____

Raw Materials During Inspection ___________________________
____
____

Fuels During Inspection _________________________________
____
____
____

TABLE A-2 (continued)

J Fabric Filter Evaluation

Inspection No. ____________

Equipment No. ____________

Confidential: Yes ____ No ____

Page No. ______ of ______

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
D. Cleaning System						
1. Filter house pressure drop high			E		5	If sum (Σ) of ratings is ≥10, perform internal inspection and check deposits on dirty side of bags. Check bag tension. Reschedule inspection in near future.
2. Pulse-jet air header pressure low			E		5	
3. Solenoids inoperative	N/A	N/A	E or I		10	
4. Reverse air fan inoperative	N/A	N/A	E or I		10	
5. Shaker motor inoperative	N/A	N/A	E or I		10	
6. Bag length long			E		2	
7. Equipment inaccessible	N/A	N/A	I		2	
8. High intensity cleaning required			E		2	
					Σ =	
E. Hopper						
1. Filter house pressure drop high			E		5	If sum (Σ) of ratings is ≥10 perform internal inspection of hoppers.
2. Solids-removal run intermittent	N/A	N/A	E		3	
3. Indicator level existent and/or inoperative	N/A	N/A	E		2	
4. Heaters nonexistent and/or inoperative	N/A	N/A	E		2	
5. Vibrators nonexistent and/or inoperative	N/A	N/A	E		2	
6. Hopper valves corroded	N/A	N/A	I		3	
7. Hopper slope <60°	N/A	N/A	E		2	
8. Hoppers not insulated	N/A	N/A	E		2	
9. Winter	N/A	N/A	E		2	
10. Hammer markings on hopper walls	N/A	N/A	E		2	
11. Conveyor inoperative	N/A	N/A	E		10	
					Σ =	

*Location: E is external, and I is internal.

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TABLE A-2 (continued)

J Fabric Filter Evaluation

Inspection No. ________

Equipment No. ________

Confidential: Yes ___ No ___

Page No. ____ of ____

Possible Operating Problems	Average Baseline (Specify Value)	Observed (Specify Value)	Location*	Abnormal (Check)	Rating (1-10)	Recommended Action
A. **Bag Tears or Pinholes**						
1. Filter house pressure drop low (<80% avg.)			E		3	If sum (Σ) of ratings is ≥ 10, perform internal inspection. Check for deposits on filter house clean side. Check inaccessible bags. Use fluorescent dye technique. Check integrity of fabric by attempting to extend rips.
2. Opacity high			E		5	
3. Bag age high (typical avg.)			E		5	
4. Some bags inaccessible	N/A	N/A	I		2	
5. Design A/C high (>120% avg.)			E		4	
6. Actual A/C high (>120% avg.)			E		4	
7. Wear plate eroded	N/A	N/A	I		3	
8. Frequent high excursions			E or I		4	
				Σ =		
B. **Bag Blinding**						
1. Filter house pressure drop high (>150% avg.)			E		7	If sum (Σ) of ratings is ≥10, perform internal inspection. Check dirty side of bags for coatings (this may be difficult to identify in some cases). Check records for steady rise in filter house pressure drop. Reschedule inspection in near future.
2. Opacity low			E		2	
3. Cleaning frequency high (cycles/day)			E		5	
4. Gas temp low (<20°F avg.)			E		4	
5. Moisture in gas stream	N/A	N/A	E		4	
6. Particulate sticky	N/A	N/A	E		4	
7. Air in-leakage (hoppers/ access doors)	N/A	N/A	I		2	
8. Unit not insulated	N/A	N/A	E		2	
				Σ =		
C. **Bag Bleeding**						
1. Opacity high			E		5	If sum (Σ) of ratings is ≥10 attempt to confirm uses of fluorescent dye and black light.
2. Pressure drop gradually increasing			E		2	
3. Cleaning frequency high			E		5	
				Σ =		

*Location: E is external, and I is internal.

TABLE A-2 (continued)

K Summary

Inspection No. ____________

Equipment No. ____________

Confidential: Yes ____ No ____

Page No. ______ of ______

1. CONTROL SYSTEM PERFORMANCE

System Air Flow Based on Fan Data ____________________ ACFM

System Air Flow Based on Pitot Traverse ____________________

System Air Flow Based on Process ____________________

Actual Air to Cloth Ratio ____________________

Design Air to Cloth Ratio ____________________

Fabric Compatibility with Environment ____________________

____

2. ADDITIONAL COMMENTS

____

____

____

____

____

3. SHEETS INCLUDED

A. ______ B. ______ C. ______ D. ______ E. ______ F. ______

G. ______ H. ______ I. ______ J. ______ K. ______

Preparer: Name ____________________ Signature ____________

Date ____________________

Reviewer: Name ____________________ Signature ____________

Date ____________________

Copies Received ______ Initials ______ Date ____________

TABLE A-2 (continued)

Fabric Filter Supplemental Information

Inspection No. ________

Equipment No. ________

Confidential: Yes ___ No ___

Page No. _____ of _____

TABLE A-3. WET SCRUBBER INSPECTION DATA SHEET.

LOCATION ______________________

DESIGNATION ______________________

DATA SHEET NO. ______________

DATE ______________________

INSPECTOR(S) ______________

INSPECTION NO. ______________

CLAIMED
CONFIDENTIAL Yes _____ No _____

A. DESCRIPTIVE INFORMATION

Wet Scrubber Type ______________________________

Manufacturer ______________________________

Model Number ______________________________

Date Installed ______________________________

Process/Source Controlled ______________________

Particulate Characteristics ______________________

B. COMPONENT INFORMATION (Describe if applicable)

1. Gas Pretreatment:

Presaturator ______________________

Cyclones ______________________

Settling Chamber ______________________

Other ______________________

2. Demister:

Cyclone ______________________

Chevron ______________________

Fiberous Mat ______________________

Other ______________________

3. Pumps:

Number ______________________

Recirculation
Pump Manufacturer ______________________

Recirculation
Pump Rated Horsepower ______________________

Recirculation Pump Type ______________

TABLE A-3 (continued)

Inspection No. __________
Data Sheet No. __________
Preparer ______________
Confidential: Yes__ No__

B. COMPONENT INFORMATION (continued)

4. Fan/Motor (Specify)
Fan Manufacturer ______________________________
Blade Type: Radial ____ Backward ___ Forward ____
Drive: Direct ______________ Belt ________________
Damper Position ______________________________
Motor Manufacturer ___________________________
Model No. ____________________________________
Rated Horsepower _____________________________
Location: Forced Draft _____ Induced Draft ______

5. Instrumentation (Check if Applicable)

Differential Pressures:	Throat	_______________
	Separator	____________
	Demister	_____________
Temperatures:	Gas Outlet	____________
	Gas Inlet	____________
	Liquor Inlet	_________
	Liquor Outlet	________
pH:	Recirculation	________
	Exit Liquor	__________
	Fan Motor Current	____
	Other	________________
	Nozzle Pressure	______
Flow Rates:	Recirculation	________
	Makeup	_______________
	Purge	________________
Motor Current:	Fan	__________________
	Pump	_________________

TABLE A-3 (continued)

Inspection No. ___________
Data Sheet No. ___________
Preparer _______________
Confidential: Yes__ No__

B. COMPONENT INFORMATION (continued)

6. Materials of Construction (Specify type and gauge)
Presaturator ________________________________
Throat ________________________________
Scrubber Shell ________________________________
Trays/Bed Supports ________________________________
Demister ________________________________
Fan Housing ________________________________

TABLE A-3 (continued)

Inspection No. ____________

Data Sheet No. ____________

Preparer ________________

Confidential: Yes__ No__

C. DIAGRAM

1. Sketch wet scrubber system. (Show all major components and processes controlled.)

2. Sketch wet scrubber layout (each square 1' x 1')

TABLE A-3 (continued)

Inspection No. ____________
Data Sheet No. ____________
Preparer ________________
Confidential: Yes__ No__

F. SAMPLE ANALYSIS

Scrubber Liquor Effluent

Sample No. ______________________________
Location Obtained ______________________
Date/Time Obtained _____________________
Results:
Suspended Solids _______________________ ppm
Dissolved Solids _______________________ ppm
pH ____________________________________
Chloride ______________________________ ppm

Scrubber Recirculation

Sample No. ______________________________
Location Obtained ______________________
Date/Time Obtained _____________________
Results:
Suspended Solids _______________________ ppm
Dissolved Solids _______________________ ppm
pH ____________________________________
Chloride ______________________________ ppm

Other

____
____
____
____
____
____

TABLE A-3 (continued)

Inspection No. ________
Data Sheet No. ________
Preparer ____________
Confidential: Yes__ No__

G. CONTROL SYSTEM PERFORMANCE

Gaseous Flow (implied from fan operation) ________________ ACFM
Gaseous Flow (calculated from pitot traverse) ________________ ACFM
Gaseous Flow (implied from process operation) ________________ ACFM
Liquor Flow ________________ gpm
L/G Ratio ________________
Bypass (% of total gas flow) ________ %
Throat Velocity ________________ FPS
Superficial Velocity (design) ________ FPM
(effective) ________ FPM
Visible Emissions (residual) ________ %

H. ADDITIONAL COMMENTS

____
____
____
____
____
____

Sheets Included: A ___ B ___ C ___
D ___ E ___ F ___
G ___ H ___

Inspector's Signature ____________
Date Prepared ____________
Reviewer's Signature ____________
Date Reviewed ____________
Date Filed ____________

TABLE A-4. ELECTROSTATIC PRECIPITATOR INSPECTION DATA SHEET.

A. INSPECTION INFORMATION

1. IDENTIFICATION

Company____
Plant Name______________________________________
Plant I.D. Number__________________________________
Address____
____
____
Control Device/System Number__________________________
Process Served____________________________________

2. PROCEDURES AND CONDITIONS

Prior Notice: Yes______ No______
Time(s) On-Site___________________________________
____
Type Inspection___________________________________
____
Inspectors______________________________________
____
____
Plant Representatives______________________________
____
____
Information Claimed Confidential: Yes______ No______

TABLE A-4 (continued)

B. Visible Emissions Observations

Inspection No.__________
Equipment No.__________
Confidential: Yes___ No___
Page No.______ of ______

1. STACK CHARACTERISTICS

Location____________________
Height____________________
Temperature____________________
Exit Dimensions____________________
Orientation____________________
Other Information____________________

2. STACK EFFLUENT

Detached Plume: No______ Yes______ Distance____________
Color____________________
Puffing: Yes____________ No____________
Opacity

Time	Average Opacity	Observation Point	Sheet No.

3. FUGITIVE EMISSIONS

Control Device: Yes______ No______
Solids Removal System: Yes______ No______
Process: Yes______ No______
Continuous____________ Intermittent____________
Adjacent Deposits: Yes______ No______

TABLE A-4 (continued)

Inspection No.____________

Equipment No.____________

Confidential: Yes____ No____

Page No. _____ of _____

C. Fan Data

1. FAN MOTOR

Manufacturer____________________

Model No.____________ Type____________

Rated Horsepower____________________

Volts____________ Maximum Amps____________

Maximum R.P.M.____________ Service factor____________

Operating Current: Panel____________ Other____________

2. DRIVE

Direct____________Belt____________Other____________

Sheath Reduction____________________

Audible Belt Slippage: Yes____________ No____________

3. FAN

Manufacturer____________________

Model No.____________ Type____________

Fan Vibration____________________

Gas Temperature at inlet, $^{\circ}F$____________________

Fan R.P.M.____________________

____

Fan Static Pressures: Inlet____________ Outlet____________

Differential Static Pressures: Measured______ Panel________

Fan Housing Condition____________________

Dampers____________________

Fan Exit____________________

TABLE A-4 (continued)

D. Electrostatic Precipitator Data

Inspection No.____________

Equipment No.____________

Confidential: Yes___ No___

Page No. _____ of _____

1. DESCRIPTIVE INFORMATION

Type____________________________________

Manufacturer____________________________________

Model Number____________________________________

Plant Inventory Number____________________________________

Date Installed____________________________________

Number of Chambers____________________________________

Number of Fields in Series____________________________________

Specific Collection Area (Ft²/1000 Ft³)____________________

Design Superficial Viscosity (Ft/Sec)____________________

Pulse Energization (Yes/No)____________________

2. LOCATION

Building/Area____________________________________

Elevation____________________________________

3. LAYOUT (SKETCH FIELD LAYOUT AND NUMBER FIELDS, SHOW FANS)

TABLE A-4 (continued)

E. Electrostatic Precipitator External Inspection

Inspection No.____________
Equipment No.____________
Confidential: Yes____ No____
Page No.______ of ______

1. HOPPER LAYOUT (SKETCH TOP VIEW AND NUMBER; SHOW SOLIDS HANDLING SYSTEM)

2. HOPPER DESCRIPTION

Vibrators: Yes____________ No____________
Heaters: Yes____________ No____________
Insulation: Yes____________ No____________
Level Indicators: Yes________ No________ Type________
Physical Condition (Characterize)____________

Transport Equipment: Screws______ Pneumatic______ Other______
Transport Equipment Operating: Yes________ No________
Characterize Discharge____________

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No_____
Page No.______ of ______

3. HOPPER VALVES

Type: Screw____________________ Other______________________
Speed/Cycle Times______________________________________
____
Blade Type____

4. RAPPER LAYOUT (SKETCH TOP VIEW, SHOW DISCHARGE WIRE UNITS AS D, COLLECTION PLATE UNITS AS C AND DISTRIBUTION PLATE UNITS AS X).

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No____
Page No.______ of ______

5. RAPPER PERFORMANCE (Continued)

COLLECTION PLATE RAPPERS

No.	Time Interval (Minutes)	Duration (Seconds)	Comments
C_1			
C_2			
C_3			
C_4			
C_5			
C_6			
C_7			
C_8			
C_9			
C_{10}			
C_{11}			
C_{12}			
C_{13}			
C_{14}			
C_{15}			
C_{16}			
C_{17}			
C_{18}			
C_{19}			
C_{20}			

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.____________

Equipment No.____________

Confidential: Yes____ No____

Page No.______ of ______

5. RAPPER PERFORMANCE

DISCHARGE WIRE RAPPERS

No.	Time Interval (Minutes)	Duration (Seconds)	Comments
D_1			
D_2			
D_3			
D_4			
D_5			
D_6			
D_7			
D_8			
D_9			
D_{10}			
D_{11}			
D_{12}			
D_{13}			
D_{14}			
D_{15}			
D_{16}			
D_{17}			
D_{18}			
D_{19}			
D_{20}			

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.____________
Equipment No.____________
Confidential: Yes____ No____
Page No.______ of ______

5. RAPPER PERFORMANCE (Continued)

DISTRIBUTION PLATE RAPPERS

No.	Time Interval (Minutes)	Duration (Seconds)	Comments
X_1			
X_2			
X_3			
X_4			
X_5			
X_6			

6. RAPPER DESCRIPTION

DISCHARGE WIRES

Type ____________
Number ____________
Manufacturer ____________
Air Pressure ____________

COLLECTION PLATES

Type ____________
Number ____________
Manufacturer ____________
Air Pressure ____________

DISTRIBUTION PLATES

Type ____________
Number ____________
Manufacturer ____________
Air Pressure ____________

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.______________

Equipment No.______________

Confidential: Yes____ No____

Page No.______ of ______

7. TRANSFORMER - RECTIFIER SET LAYOUT (SKETCH TOP VIEW SHOWING T-R SETS ON CHAMBERS AND FIELDS)

8. TRANSFORMER - RECTIFIER SET DESCRIPTION

Power Control: Yes______ No______

Mode Voltage____________ Current____________ Spark Rate____________

No.	Plant No.	Manufacturer	Model No.	Milliamp Rating	Type
T-R$_1$					
T-R$_2$					
T-R$_3$					
T-R$_4$					
T-R$_5$					
T-R$_6$					
T-R$_7$					
T-R$_8$					
T-R$_9$					
T-R$_{10}$					

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No____
Page No. ______ of ______

9. TRANSFORMER - RECTIFIER SET CONDITIONS

No.	Primary current (amperes)	Primary voltage (volts)	Secondary current (milliamps)	Secondary voltage (kilovolts)	Spark rate #/min	Control mode M-manual A-automatic
T-R-1a						
T-R-1b						
T-R-2a						
T-R-2b						
T-R-3a						
T-R-3b						
T-R-4a						
T-R-4b						
T-R-5a						
T-R-5b						
T-R-6a						
T-R-6b						
T-R-7a						
T-R-7b						
T-R-8a						
T-R-8b						
T-R-9a						
T-R-9b						
T-R-10a						
T-R-10b						

TABLE A-4 (continued)

E. Electrostatic Precipitator
External Inspection

Inspection No.____________

Equipment No.____________

Confidential: Yes____ No____

Page No.______ of _____

10. OPERATING INFORMATION

Gas Inlet Temperature, °F______________________________

Hopper Heater Operational Indicator Lights (Identify units not on)

____

Penthouse Heater/Blower Operational Indicator Lights (Identify units not on)____

____

Comments____

____

____

____

11. OPACITY MONITORS

Opacity - Minimum, % ________________

Average, % ________________

Maximum, % ________________

Spikes (Characterize Frequency, Duration, Intensity)__________

____

____

____

Calibration Spikes (Characterize Levels, Frequency)__________

____

____

Comments____

____

____

TABLE A-4 (continued)

F. Electrostatic Precipitator Interal Inspection

Inspection No.__________
Equipment No.__________
Confidential: Yes____ No____
Page No.______ of ______

1. PURPOSE

Reason(s) Necessary____________________

____

____

SAFETY EVALUATION

Lockout Procedure Followed____________________
Plant Employee Performing Lockout____________________
Grounding Straps Available: Yes__________ No__________
Time Period De-energized (Hours)____________________
Purge Completed: Yes__________ No__________
O_2, %____________________
Combustibles, %____________________
Noise____________________
Other____________________
Inspection Not Conducted Due to Potential Hazards (Characterize)

____

____

2. AREAS INSPECTED (SKETCH TOP VIEW AND INDICATE ENTRY POINTS)

TABLE A-4 (continued)

F. Electrostatic Precipitator
Internal Inspection

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No____
Page ______ of ______

3. HATCH CONDITIONS

Gaskets____

Corrosion____

4. PENTHOUSE CONDITIONS

Purge Air____

Heater(s)____

Insulators____

Alignment of Collection Plates________________________

Comments____

TABLE A-4 (continued)

F. Electrostatic Precipitator Internal Inspection

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No____
Page No.______ of ______

5. ELECTRODE CONDITIONS

DISCHARGE WIRES

Type______________________________
Diameter______________________________
Material______________________________
Spacing and Length______________________________
Conditions______________________________

COLLECTION PLATES

Type______________________________
Material______________________________
Spacing and Length______________________________
Conditions______________________________

Alignment______________________________

TABLE A-4 (continued)

F. Electrostatic Precipitator Internal Inspection

Inspection No.________________

Equipment No.________________

Confidential: Yes____ No____

Page No.______ of ______

6. INTERNAL SUPPORTS

Describe____

Conditions____

7. GAS DISTRIBUTION EQUIPMENT

Type____

Condition____

8. HOPPERS

Baffle Condition____

Hopper Condition____

TABLE A-4 (continued)

G. Continuous Monitor Evaluation

Inspection No.______________
Equipment No.______________
Confidential: Yes____ No____
Page No.______ of ______

1. DESCRIPTIVE DATA

Manufacturer______________________________
Model______________________________
Type______________________________
Date Installed______________________________
Single or Multiple Breeching (Describe Sources)______________
____
____

NSPS Applicable: Yes______________ No______________

2. TRANSMISSOMETER

LAYOUT (SHOW LOCATION RELATIVE TO FLOW RESTRICTIONS)

TABLE A-4 (continued)

G. Continuous Monitor Evaluation

Inspection No.______________

Equipment No.______________

Confidential: Yes____ No____

Page No.______ of ______

2. TRANSMISSOMETER (Continued)

Approximate Path Length, (Feet)______________________________

Mounting (Characterize)______________________________

____

Vibration (Characterize)______________________________

____

Housing (Characterize)______________________________

____

Purge Air (Condition of Blowers and Hoses)______________

____

____

Filters (Characterize Type and Describe Condition)__________

____

Alignment (Window Check)______________________________

____

3. CONSOLES

Breeching/Stack Correlation______________________________

____

Zero/Span______________________________

____

Comments______________________________

____

____

____

TABLE A-4 (continued)

H. Electrostatic Precipitator Evaluation

Inspection No.______________

Equipment No._______________

Confidential: Yes____ No____

Page No.______ of ______

1. FILES/ADMINISTRATIVE

Specification Sheets Available: Yes___________ No____________

Prints Available (Characterize)_____________________________

____

Supervisor of Unit____

O and M Personnel (Describe Staff and Organization)____________

____

____

2. RECORDKEEPING

Type Records____

____

Operating Records (List Parameters)__________________________

____

Diagnostic Records (Characterize)____________________________

____

____

____

3. PROCEDURES

Spare Parts Inventory (Characterize)_________________________

____

____

O&M Plan (Characterize)______________________________________

____

____

____

Troubleshooting (Characterize)_______________________________

____

____

TABLE A-4 (continued)

I. Samples

Inspection No.______________
Equipment No._______________
Confidential: Yes____ No____
Page No.______ of ______

1. Solids

Sample No.____
Location Obtained__________________________________
Date/Time Obtained_________________________________
Results____

2. Other Samples

Sample No.____
Location Obtained__________________________________
Date/Time Obtained_________________________________
    Permeability_________________________________
    Tensile Strength_____________________________
    Count____
    Weight/Yard^2________________________________

3. Other____

TABLE A-4 (continued)

J. Electrostatic Precipitator Evaluation

Inspection No.____________
Equipment No.____________
Confidential: Yes____ No____
Page No.______ of ______

1. POWER INPUT

Collection Plate Area/Field
Inlet____
Other____
Discharge Wire Length/Field
Inlet____
Other____

Field	Secondary Currents (Milliamps)	Power Input (Watts)	Current Densities (Milliamps/Ft)	Current Densities Watts/Ft²
1.				
2.				
3.				
4.				
5.				
6.				
7.				
8.				
9.				
10.				
11.				
12.				
13.				
14.				
15.				

TABLE A-4 (continued)

K. Process

Inspection No.______________

Equipment No.______________

Confidential: Yes____ No____

Page No.______ of ______

1. PROCESS TYPE

Characterize Source____________________________________

Operating Schedule____________________________________

2. OPERATION

Product Type During Inspection__________________________

Production Data During Inspection_______________________

Raw Materials During Inspection_________________________

Fuels During Inspection________________________________

TABLE A-4 (continued)

L.Summary

Inspection No.____________
Equipment No.____________
Confidential: Yes____ No____
Page _____ of _____

1. POWER INPUT____________________

2. MECHANICAL____________________

3. SOLIDS REMOVAL____________________

4. EFFLUENT QUANTITY/CHARACTERISTICS____________________

5. OTHER____________________

6. SHEETS

A._______ B._______ C._______
D._______ E._______ F._______
G._______ H._______ I._______
J._______ K._______

Preparer: Name________________ Signature________________
Date________________

Reviewer: Name________________ Signature________________
Date________________

Copy Received: Initials____________ Date________________

TABLE A-5. MECHANICAL COLLECTOR INSPECTION DATA SHEET.

LOCATION ______________________ DATA SHEET NO. ______________

DESIGNATION __________________ INSPECTION NO. ______________

CLIENT ________________________ INSPECTOR(S) ______________

PN ____________________________ DATE ______________________

CLAIMED
CONFIDENTIAL Yes _____ No _____

A. DESCRIPTIVE INFORMATION

Mechanical Collector Type

Cyclone __________ Settling Chamber __________

Cyclone Bank _____ Double Vortex Cyclone _____

Multiclone _______ Other (describe) __________

____

Manufacturer ______________________________

Model Number ______________________________

Date Installed ______________________________

Process/Source Controlled ______________________________

Particulate Characteristics ______________________________

____

B. COMPONENT INFORMATION

1. Cyclone

Diameter of Body ______________________________ ft.

Cone Angle ______________________________ degrees

Material of Construction ______________________________

Gauge of Metal ______________________________

Number of Cyclones ______________________________

2. Hoppers

Number ______________________________

Slope ______________________________

Insulation: Yes ______________ No ______________

Heating: Yes ______________ No ______________

Vibrators: Yes ______________ No ______________

TABLE A-5 (continued)

Inspection No. ________

Data Sheet No. ________

Preparer ________

Confidential: Yes__ No__

B. COMPONENT INFORMATION (continued)

3. Solids Removal (Check applicable items and provide dimensions)

Rotary Valves ________

Flapper Valves ________

Screw Conveyors ________

Pneumatic Conveyors ________

Free Fall ________

4. Fan/Motor

Fan Manufacturer ________

Model Number ________

Blade Type: Radial ____ Backward ____ Forward ___

Drive: Direct ________ Belt ________

Motor Manufacturer ________

Model Number ________

Rated Horsepower ________

RPM ________

Location: Forced Draft _____ Induced Draft _____

C. SYSTEM LAYOUT

TABLE A-5 (continued)

Inspection No. __________
Data Sheet No. __________
Preparer ________________
Confidential: Yes__ No__

D. EXTERNAL INSPECTION

Fan Inlet Static Pressure ______________________ in. of H_2O
Fan Outlet Static Pressure _____________________ in. of H_2O
Fan Motor Current ______________________________ amperes
Fan Rotational Speed ___________________________ rpm
Fan Damper Position ____________________________
Gas Temperature at Fan Inlet ___________________ °F
Fan Vibration (low, moderate, severe) __________
Static Pressure at Collector Outlet ____________ in. of H_2O
Static Pressure at Collector Inlet _____________ in. of H_2O
On-site Differential Pressure Gauge Reading _____ in. of H_2O
Gas Temperature at Collector Inlet _____________ °F
Rotary Valve Rotational Speed __________________ rpm
Flapper Gate Frequency _________________________ (#/hr)
Hopper Conditions (Check if applicable)

Cold ________
Dented ______
Warped ______
Corroded ____

TABLE A-5 (continued)

Inspection No. ___________

Data Sheet No. ___________

Preparer ________________

Confidential: Yes__ No__

E. INTERNAL INSPECTION

Hoppers (plugged or corroded) ____________________________

Hopper Baffles Nonexistent (Characterize potential abrasion) ____________________________

Inlet Vanes Plugged/Eroded (Characterize severity) ____

Cones Plugged (location, number) ____________________________

Flow Disturbances (Characterize severity) ______________

Outlet Tube Erosion (Characterize potential bypassing)

Corrosion (Characterize) ____________________________

Scaling (Characterize) ____________________________

TABLE A-5 (continued)

Inspection No. __________
Data Sheet No. __________
Preparer ________________
Confidential: Yes__ No__

F. CONTROL SYSTEM PERFORMANCE

Air Flow Rate (implied from fan operation) ____________ ACFM
Air Flow Rate (calculated from pitot tube) ____________ ACFM
Air Flow Rate (implied from process operation) ________ ACFM
Inlet Velocity ______________________________________ FPS
Opacity ____ %

G. ADDITIONAL COMMENTS

____
____
____
____
____
____

Sheets Included: A___ B__ C___ D__
E___ F__ G___

Inspector's Signature ______________
Date Prepared ______________________
Reviewer's Signature _______________
Date Reviewed ______________________
Date Filed _________________________

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-450/1-84-025	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Coal-Fired Industrial Boiler Inspection Guide		5. REPORT DATE Issued January 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) William E. Gallagher, Gerald A. Isaacs, Thomas C. Ponder, Jr., and Robert A. Ressl		8. PERFORMING ORGANIZATION REPORT NO. 3560-3-9
9. PERFORMING ORGANIZATION NAME AND ADDRESS PEDCo Environmental, Inc. 11499 Chester Road Cincinnati, Ohio 45246-0100		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO. 68-01-6310
12. SPONSORING AGENCY NAME AND ADDRESS		13. TYPE OF REPORT AND PERIOD COVERED Final
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
U.S. EPA Project Officer - John R. Busik, Stationary Source Compliance Division

16. ABSTRACT

This document provides guidance for evaluating the performance of coal-fired industrial boilers relative to a pollution control agency's particulate air pollution control rules and regulations. The guidance and checklists in this document enable an air pollution control agency inspector to check a boiler operation quickly and efficiently. A thorough description of stoker-fired and pulverized coal-fired industrial boilers helps prepare the inspector for the field inspection. Pollution control equipment typically used on industrial boilers (multicyclones, fabric filters, electrostatic precipitators, and scrubbers) is described as well as common problems and possible solutions that influence the operation and maintenance of these devices.

Baseline data for a boiler and its pollution control equipment normally are established during a compliance stack test. Information contained in this report shows the agency inspector how to compare current boiler operations to the baseline data for a compliance determination. This is particularly useful when a clearly defined cause-and-effect relationship cannot be established for a given source.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Boilers	Industrial, Stoker-fired, Pulverized Coal-fired	13A
Pollution	Air Pollution Control	13B
Particles	Particulate Emissions	14G
Control Equipment	Multicyclones, Fabric Filters, ESPs, Scrubbers	13B

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